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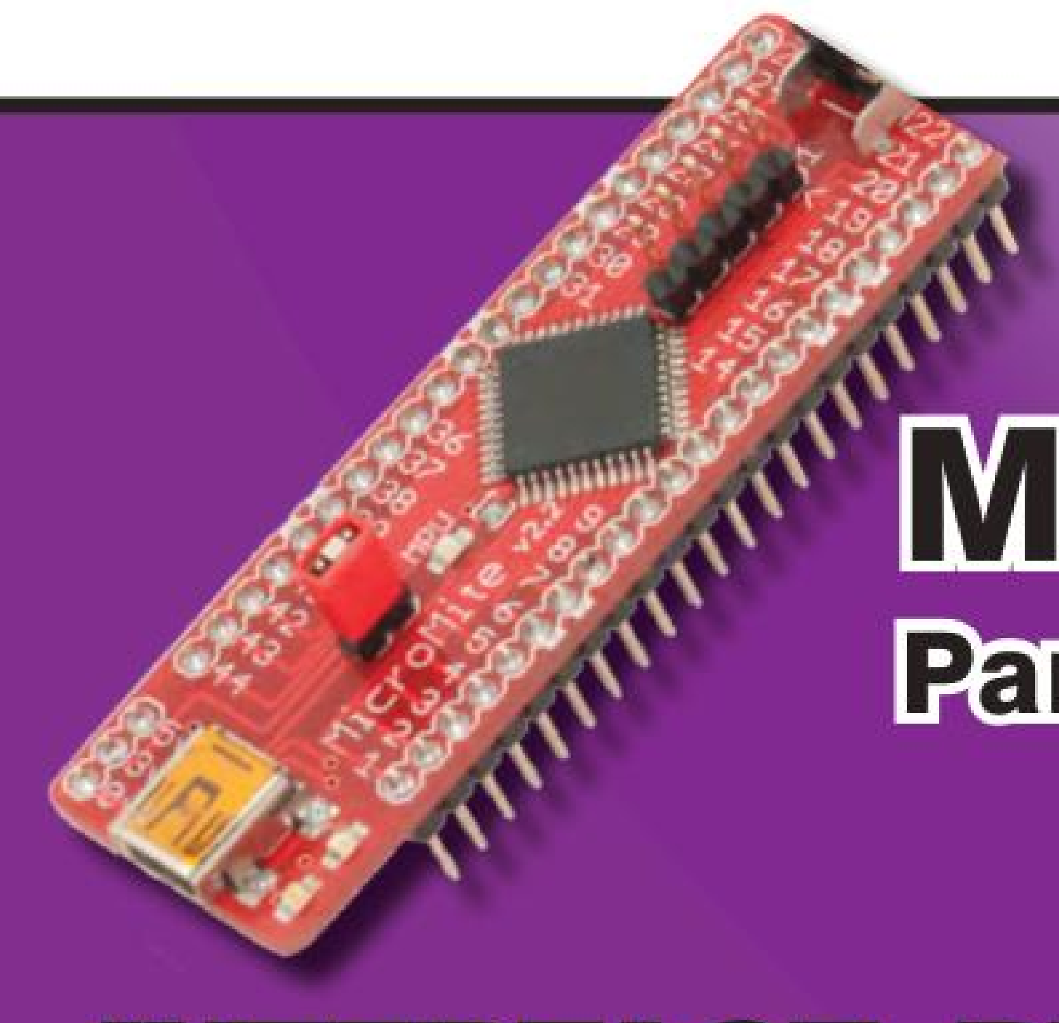

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Experimenting with PIR and RF Data
Peter Brunning
Brunning Software

### by Peter Brunning

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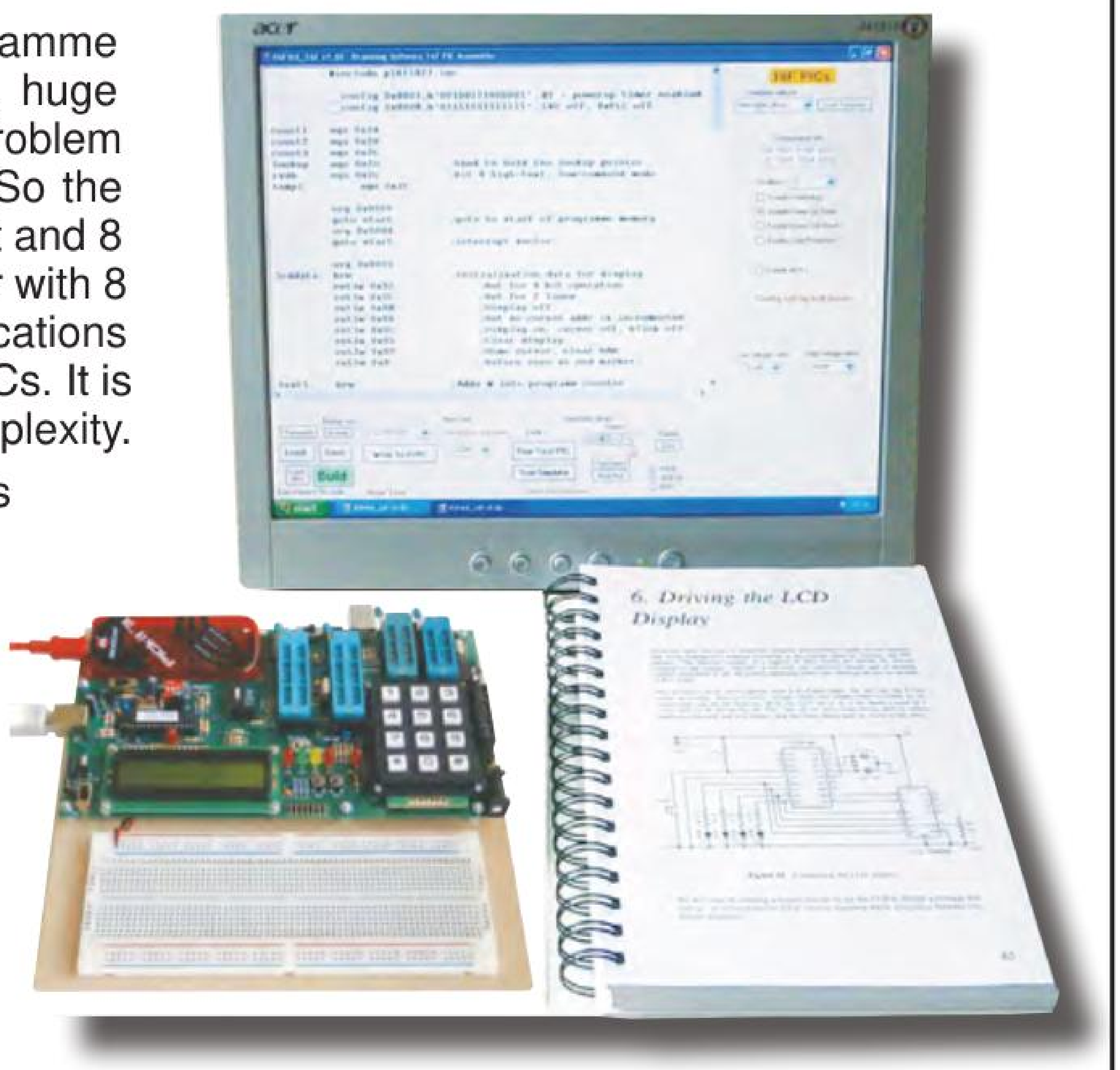

32 bit PICs are massive in all respects. Huge amounts of programme memory, huge amounts of temporary storage memory (RAM), huge amounts of input/outputs, and very fast processing speeds. The problem is that 32 bit PICs are far too complex for absolute beginners. So the P955H training circuit has been designed to work with both 32 bit and 8 bit PICs. The idea is to start learning about PICs using assembler with 8 bit PICs. Then learn C with 8 bit PICs, study serial communications using 8 bit PICs, and finally study C programming using 32 bit PICs. It is a simple approach to a subject that has no limit to its ultimate complexity.

The first book starts by assuming you know nothing about PICs but instead of wading into the theory we jump straight in with four easy experiments. Then having gained some experience we study the basic principles of PIC programming., learn about the 8 bit timer, how to drive the alphanumeric liquid crystal display, create a real time clock, experiment with the watchdog timer, sleep mode, beeps and music. Then there are two projects to work through. In the space of 24 experiments two project and 56 exercises we work through from absolute beginner to experienced engineer level using the latest 8 bit PICs (16F and 18F).

The second book introduces the C programming language for 8 bit PICs in very simple terms. The third book Experimenting with Serial Communications teaches Visual C# programming for the PC so that we can create PC programmes to control PIC circuits.

In the fourth book we learn to programme 32 bit MX PICs using fundamental C instructions. Flash the LEDs, study the 16 bit and 32 bit timers, and write text to the LCD. This is all quite straightforward as most of the code is the same as already used with the 8 bit PICs. Then life gets more complex as we delve into serial communications with the final task being to create an audio oscilloscope with advanced triggering and adjustable scan rate.

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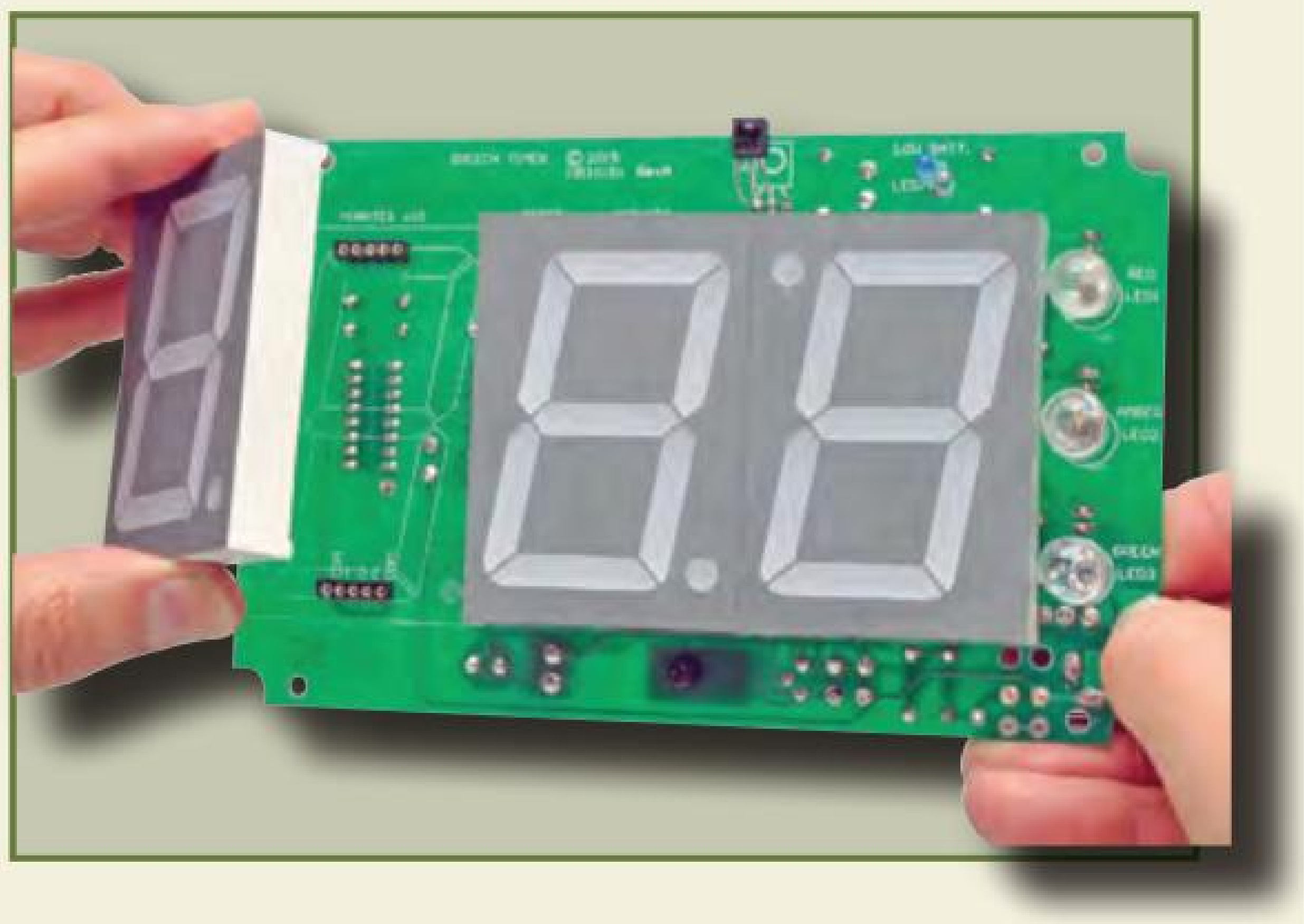

EPE product review
LabNation
SmartScope
LabNation

Meet the mighty
Micromite
Part 2: Input/output
and special devices

## Projects and Circuits

**SPEECH TIMER FOR CONTESTS & DEBATES** 12
by John Clarke
Keep meetings, speeches and events on track with this large-digit timer

**SOLAR MPPT CHARGER & LIGHTING CONTROLLER – PART 2** 24
by John Clarke
Build and set-up procedure for our superb charger/lighting control system

**ARDUINO-BASED FRIDGE MONITOR AND DATA LOGGER** 30
by Somnath Bera
Track and log temperature/humidity remotely using a 433MHz transmitter

**INGENUITY UNLIMITED** 34
Sine/square wave oscillator 10-100kHz... Heat trick

## Series and Features

**TECHNO TALK** by Mark Nelson 11
Visible light reveals dark secrets

**MEET THE MIGHTY MICROMITE** 37
by Geoff Graham
Part 2: Input/output and special devices

**NET WORK** by Alan Winstanley 44
Traditional Values... Helping hands

**CIRCUIT SURGERY** by Ian Bell 46
Direct Digital Synthesis and filtering

**PIC n' MIX** by Mike O'Keeffe 50
PICs and the PICkit 3: LED binary clock

***EPE* PRODUCT REVIEW** by Mike Tooley 54
LabNation SmartScope

**INTERFACE** by Robert Penfold 59
Analogue signal conditioning

**MAX'S COOL BEANS** by Max The Magnificent 66
Ooh, shiny!… A bit of a Brainiac... Neurotic neurons

**ELECTRONIC BUILDING BLOCKS** by Julian Edgar 68
High five!

## Regulars and Services

**SUBSCRIBE TO *EPE*** and save money 4

***EPE* – MICROCHIP SPECIAL OFFER – NOT TO BE MISSED!** 5

**EDITORIAL** 7
Air wiring... Teach-In 2017... A couple of ooops!

**NEWS** – Barry Fox highlights technology's leading edge 8
Plus everyday news from the world of electronics

**MICROCHIP READER OFFER** 36
*EPE* Exclusive – Win one of two Microchip Curiosity PIC32MX470 Development Boards

**FARNELL element14 OFFER** 45
*EPE* Exclusive – NXP WaRP7 Next Generation Internet Of Things and Wearable Development Platform

***EPE* CD ROMS FOR ELECTRONICS** 62
A wide range of technical books available by mail order, plus more CD-ROMs

***EPE* BACK ISSUES CD-ROM** 65

***EPE* PCB SERVICE** 70
PCBs for *EPE* projects

**ADVERTISERS INDEX** 71

**NEXT MONTH! –** Highlights of next month's *EPE* 72

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*Our April 2017 issue will be published on Thursday 2 March 2017, see page 72 for details.*

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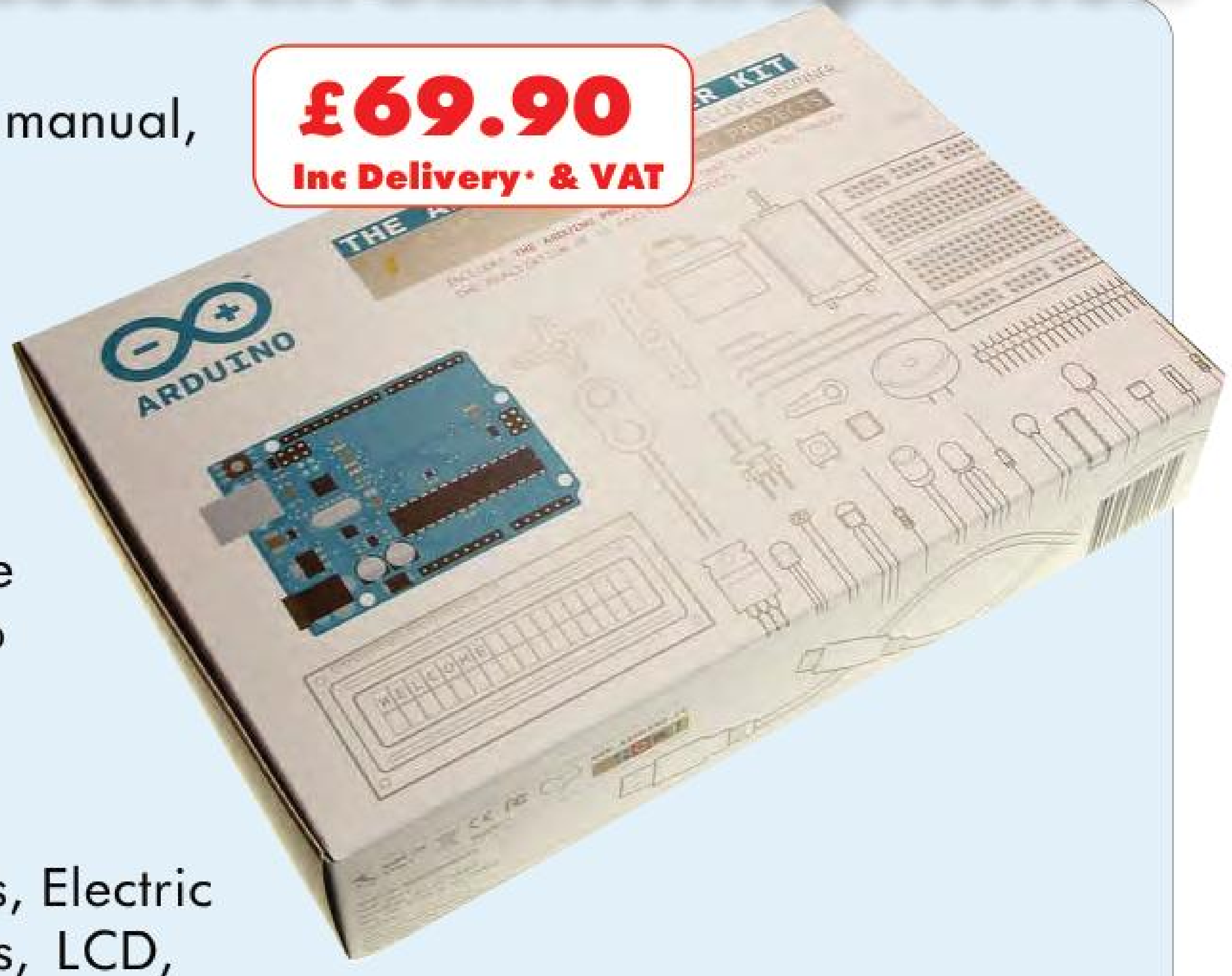

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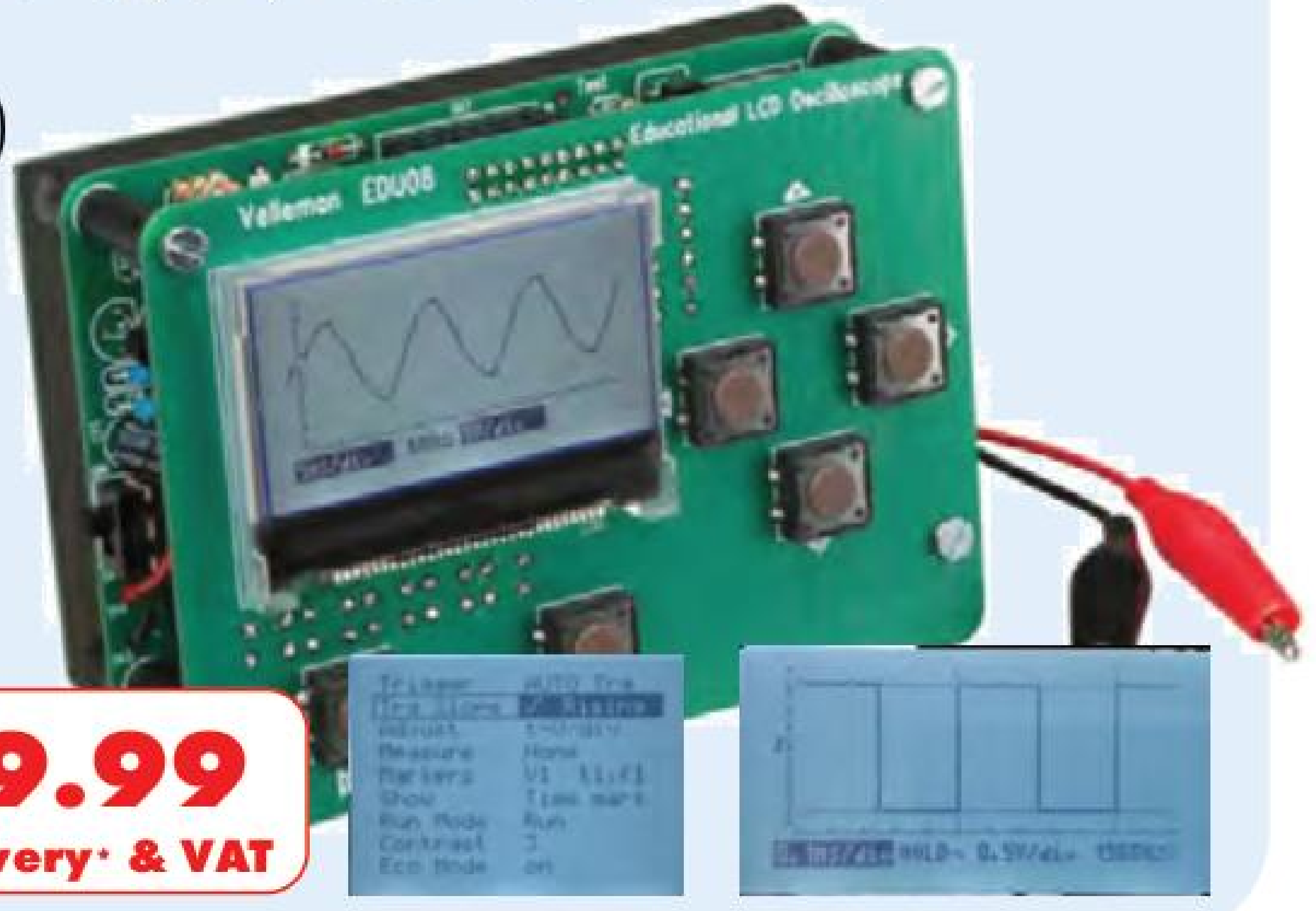

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EDITORIAL Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
**Phone:** 01202 880299. **Fax:** 01202 843233.
**Email:** fay.kearn@wimborne.co.uk
**Website:** www.epemag.com
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**Email:** stewart.kearn@wimborne.co.uk

**Editor:** MATT PULZER
**Subscriptions:** MARILYN GOLDBERG
**General Manager:** FAY KEARN
**Graphic Design:** RYAN HAWKINS
**Editorial/Admin:** 01202 880299
**Advertising and Business Manager:** STEWART KEARN 01202 880299
**On-line Editor:** ALAN WINSTANLEY

**Publisher:** MIKE KENWARD

**READERS' TECHNICAL ENQUIRIES**
**Email:** fay.kearn@wimborne.co.uk
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EPE EVERYDAY PRACTICAL ELECTRONICS

## Air wiring

Welcome to the March issue of *EPE*. I'd not come across the term 'air wiring' until I read Max's *Cool Beans* blog this month. Neat wiring always delivers a nice little 'job well done' boost to one's day, but the examples by Gislain Benoit quoted by Max really are work's of art. We'd love to see more of this kind of creativity. So if you have 'air wired' an amplifier, PIC circuit or anything else, then do let us know and share a photo or two.

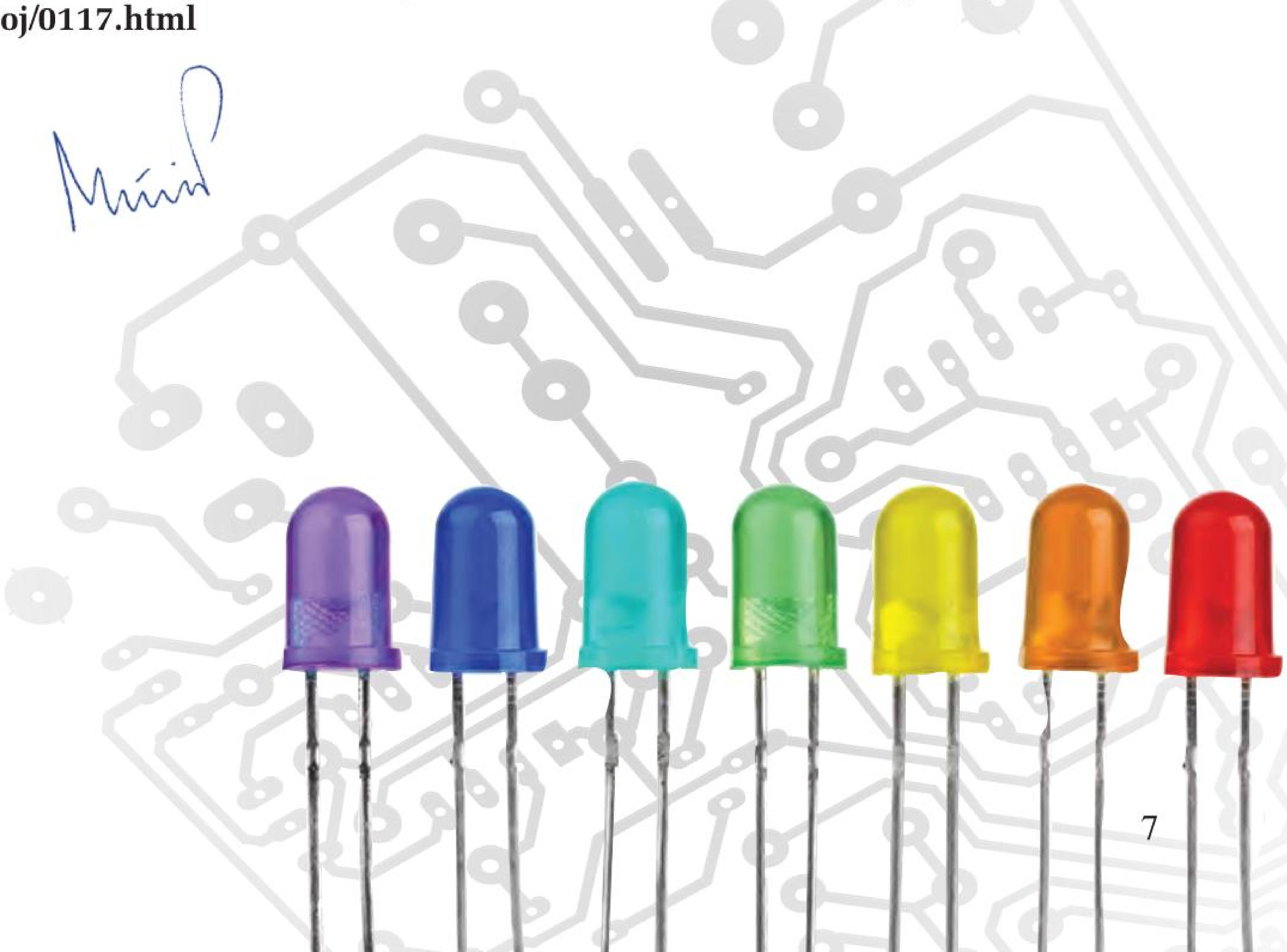
## Teach-In 2017

I briefly touched on *Teach-In 2017* in December's *Editorial*, and I am pleased to say that after much email discussion we have agreed with Mike and Richard Tooley the next *Teach-In* topic. In fact, we have agreed the next three topics, but I'll cover just the next two here. After our *Meet the mighty Micromite* series concludes next month, the Tooleys will run a 'mini Teach-In' series on the BBC micro:bit. This is a simple, clever and cheap device that is poplar in schools. For those just starting out in electronics it will be an ideal route into intelligent digital electronics. After that, probably at the end of summer, we will launch *Teach-In 2018*, which will look at... Well, I won't spoil the fun – you'll just have to wait. It will mark a change from our recent focus on microcontrollers, and will examine a subject that I guarantee all readers will find relevant and enjoy.

## A couple of ooops!

We need to make readers aware of a couple of mistakes that crept into recent issues. For those of you contemplating buying a Micromite, you may have been left a little confused by our entry at the top of the light red box on page 50 of last month's issue – 'Micromite sources'. We have decided not to sell Micromite-related devices from the *EPE* shop since the official UK supplier can offer much more experienced advice and support than we could hope to offer. If you are a purchaser in the UK then we strongly recommend you go to **micromite.org** for all your Micromite requirements. For unprogrammed PICs, then of course Microchip, Farnell/element14 and RS will meet your needs.

Second, our friends at *Silicon Chip* magazine have informed us of a small error in the *5-element Yagi DAB Antenna* project (*EPE*, January 2017). In the upper left of Fig.1, the point where the folded dipole connects to the boom is labelled 'A', when it should be labelled 'F'. For those of you building the antenna, a corrected diagram can be accessed at: **www.epemag.com/proj/0117.html**



# NEWS

A roundup of the latest Everyday News from the world of electronics

## Samsung's battery woes – report *by Barry Fox*

Samsung's Galaxy Note 7 is now officially dead – killed by its fire-prone lithium batteries. Although Samsung has offered very little technical information on what went so badly wrong, several recently published patent filings from the company's HQ in Korea reveal in delightfully frank language how the company has been trying for years to improve the safety of its rechargeable or 'secondary' batteries. And if an electronics giant with the engineering skill of a Samsung has been struggling, then you can be sure that other big companies have been struggling too.

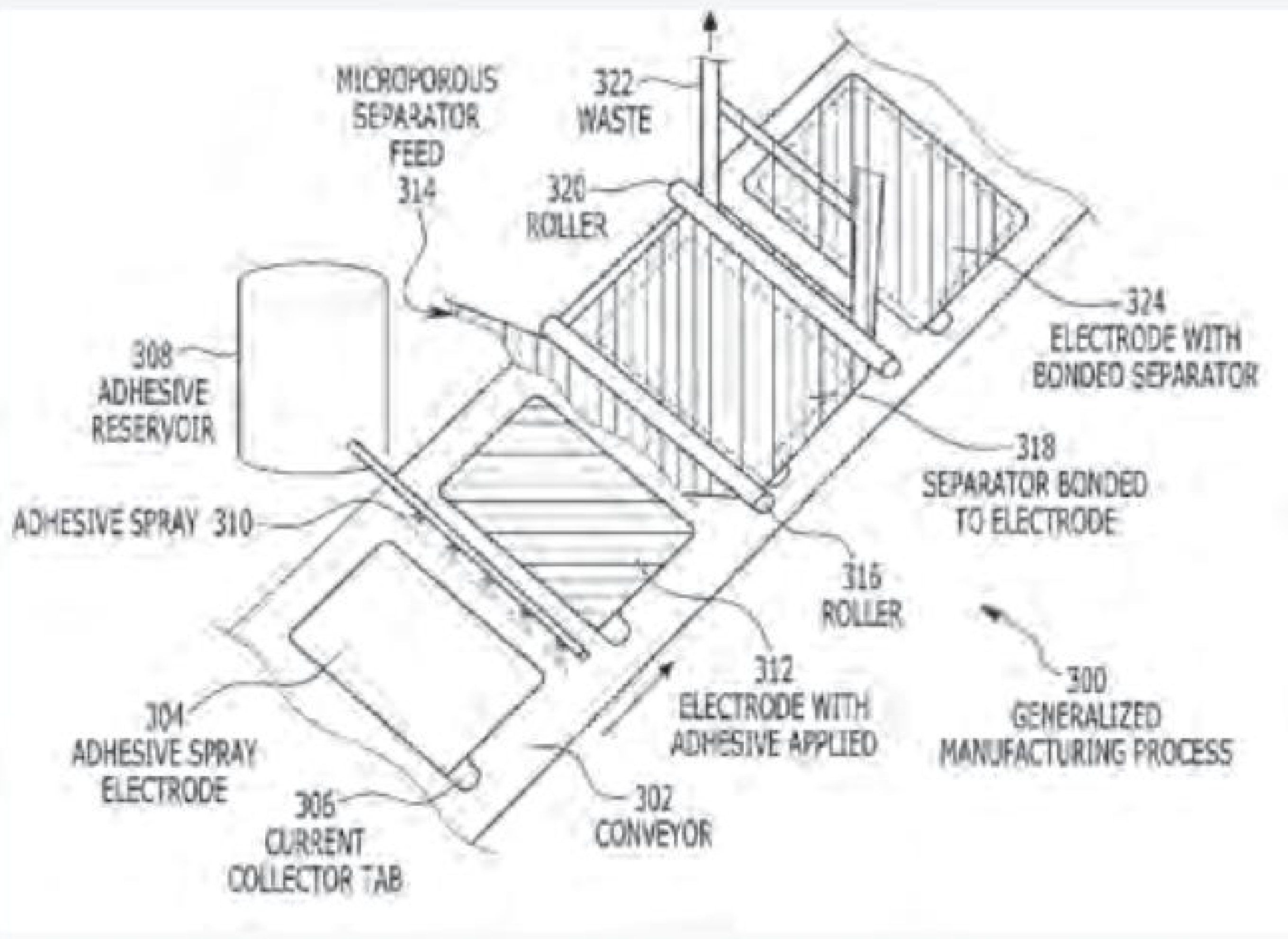
### Short circuit issue

Samsung's patent US 2016/0152874 dates from May 2009 and was published in June 2016. Hidden behind the deceptively dull title, *Treatment and Adhesives for Microporous Membranes* is a neat sum-up of the dilemma now facing designers who need to squeeze more stored power into smaller spaces: 'An electrochemical cell, such as a battery… may have anode and cathode electrodes separated by a separator film. In general, the more closely the electrodes are spaced, the higher the performance of the cell. However, when the electrodes touch each other, they may short. A short may render the cell inoperable, as well as cause a fire or other destruction when a short occurs while the cell is energized.'

Samsung's patent US 2016/0226275, on an *Overcharge protection apparatus for battery pack and overcharge protection system* reminds that overcharging can lead to a 'fire' or 'smoke' and tells how to prevent it with a belt-and-braces, two-layer charge monitoring system; separate internal and external sensors are able to trigger cut-off.

### Liquid vs solid

By a neat, but unhappy coincidence, Samsung's patent US 2016/0248120, on an *All Solid Secondary Battery and Method of Manufacturing Same* was published 25 August 2016, just as the first reports of Note 7 fires were emerging. This patent explains why solid-state lithium batteries are safer than ones which contain liquids: 'Since lithium ion batteries that have been commercialized include electrolytes including combustible organic solvents, there is a possibility of an adverse event which includes combustion when there is a short circuit. Accordingly, there remains a need for an improved solid-state battery using a solid-state electrolyte instead of a liquid electrolyte'.


MICROPOROUS SEPARATOR FEED 314
322 WASTE
320 ROLLER
308 ADHESIVE RESERVOIR
324 ELECTRODE WITH BONDED SEPARATOR
318 SEPARATOR BONDED TO ELECTRODE
ADHESIVE SPRAY 310
316 ROLLER
312 ELECTRODE WITH ADHESIVE APPLIED
300 GENERALIZED MANUFACTURING PROCESS
304 ADHESIVE SPRAY ELECTRODE
306 CURRENT COLLECTOR TAB
302 CONVEYOR

*Construction details of a battery from Samsung's patent US 2016/0152874.*

'When a short circuit occurs in a battery' the patent goes on to explain, 'there is the possibility of an adverse event, such as a fire or an explosion, which may be greatly reduced by precluding use of a combustible organic solvent in the battery. Therefore, solid-state batteries may be able to provide greatly increased safety compared to lithium ion batteries, which use liquid electrolytes'

The downside is that 'it is difficult for a solid-state battery to provide satisfactory battery characteristics. While not wanting to be bound by theory, this is understood to be because a contact between a negative electrode layer and the solid electrolyte are not sufficient, and thus a high resistance results.'

The patent's technical details are dense, but boil down to using 'pressure on the solid electrolyte in order to lower the resistance within the battery'. A dry sandwich of electrodes and electrolyte is pressed flat, with relative surface areas chosen 'to make it difficult to generate a short circuit.'

Because 'a separate structure for imparting the external pressure would be an added cost, and its mass would reduce an energy density of the solid state battery', Samsung suggests vacuum-packing the battery in foil or film so that atmospheric pressure works to compress the sandwich.

'An all solid-state battery… may significantly lower risks such as fires compared to batteries using a combustible organic electrolytic solution' the patent promises.

It will be fascinating to see how this promise ties in with whatever technical explanation for the pocket fires Samsung eventually comes out with – if the company ever does come out with a technical explanation.

### Hidden in plain view

All new technologies create new opportunities for abuse. Here's one we never saw coming. It was flagged by Lars Borg of Adobe during an erudite webinar on digital picture quality held by the Society of Motion Picture and Television Engineers (SMPTE).

### Hidden in plain view – *continued*

The latest ultra-high definition TV systems boast high dynamic range and wide colour gamut to display detail in shadows, dazzling highlights and difficult colours like Coca Cola red and Pacific Ocean blue/green.

This has left engineers with the thorny problem of making new footage look acceptable on old screens, and vice versa.

And that, the SMPTE has discovered, can lead to 'elephants in the picture'. To cut a long technical story short, mismatch between old and new TV standards can mean that studio screens fail to show coloured patterns that display clearly on some home screens.

So pictures and text can sail uncensored through the broadcast system and into homes. It's a modern and more efficient hiding trick than subliminal image flashing.

We don't yet have the tools to control it, admits the SMPTE. Even lab oscilloscopes can't check what's 'broadcast-safe'.

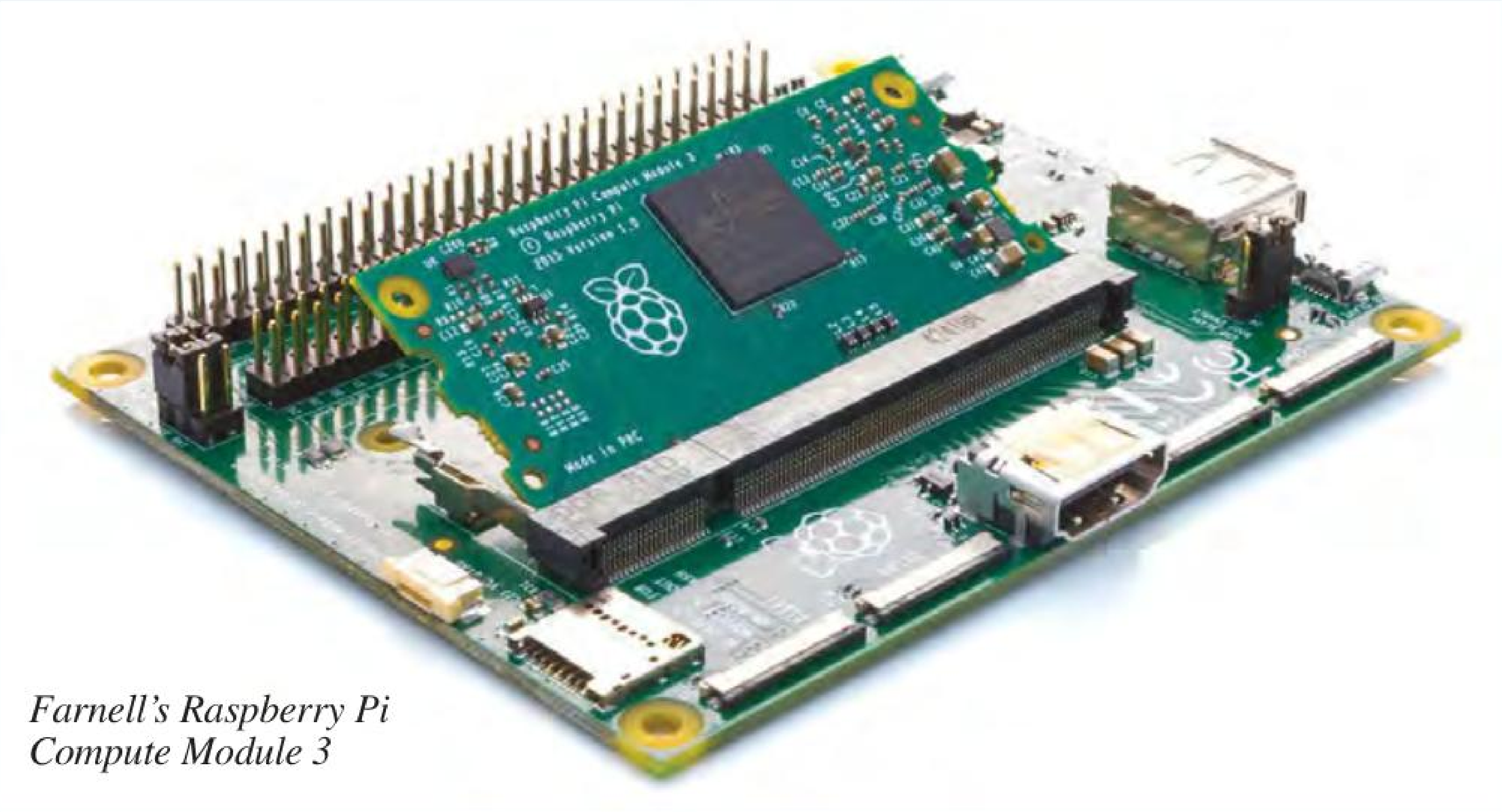
So who'll be first to use UHD for broadcasting nasty pictures, secret messages and propaganda?

## New PIC24 family

Microchip has announced its new low-power PIC24 'GA7' family of microcontrollers, '… enabling extremely cost-effective designs for Internet of Things sensor nodes, portable medical devices and industrial control applications'. The devices are supported by Microchip's MPLAB Xpress Cloud-Based IDE, which is an online development environment containing the most popular features of MPLAB X IDE. They are available in 64KB, 128KB and 256KB Flash variants with 28-pin, 44-pin and 48-pin packaging options.

More information available at: **www.microchip.com/PIC24FJ256GA705**

## Farnell launches industrial version of Pi



*Farnell's Raspberry Pi Compute Module 3*

Farnell element14 has launched three new Raspberry Pi products – the Raspberry Pi Compute Module 3, Raspberry Pi Compute Module 3 Lite and Raspberry Pi Compute Module Development kit.

The two Compute Modules (CM3 and CM3L) are DDR2-SODIMM-mechanically-compatible System on Modules (SoMs) containing processor, memory, eMMC Flash (CM3 only) and support power circuitry. They allow a designer to use the Raspberry Pi hardware and software stack for their own custom systems and form factors.

Claire Doyle, Global Head of Raspberry Pi and Single Board Computing at Premier Farnell explained that, 'The Raspberry Pi Compute Module 3 continues the development of Pi for the ever-growing industrial and commercial market. Benefiting from the Broadcom BCM2837 chip, this board allows designers to combine the speed of the Raspberry Pi 3 and the flexibility of Compute modules, enabling them to design-in Pi across a broad range of applications from IoT, to embedded solutions, home automation, control systems and consumer electronics.'

The Compute Module 3 contains the processor and the memory of the Raspberry Pi 3, with the addition of 4GB of Flash memory. This is all integrated onto a small 67.6 × 30mm board that fits into a standard DDR2 SODIMM connector. The Flash memory is connected directly to the on-board processor, leaving the remaining processor interfaces available for complete customisation. A custom IO board is available for development and testing, and is included with the Raspberry Pi Compute Module 3 Development Kit from element14.

## Printing organic electronics

New technology from the National Physical Laboratory (NPL) and the universities of Surrey, Kentucky and Southampton could revolutionise printed electronics by enabling high-quality semiconducting molecular crystals to be directly spray-deposited on any surface.

Single-crystal semiconductors, such as silicon, have been at the forefront of scientific interest for more than 70 years, serving as the backbone of electronic devices. But now a new class of crystalline materials, called organic semiconductors, can also be grown as single crystals, but in a very different way, using solution-based methods at room temperature in air, opening up the possibility of large-scale production of inexpensive electronics, targeting numerous applications ranging from FETs and LEDs to X-ray detectors and miniature lasers.

The research demonstrates for the first time a low-cost, scalable spray-printing process to fabricate high-quality isolated organic single crystals. The method is suitable for a wide variety of semiconducting small molecules, which can be dissolved in solvents to make semiconducting inks ready for printing.

'This method is a powerful, new approach for manufacturing organic semiconductor single crystals and controlling their shape and dimensions,' said Dr Maxim Shkunov from University of Surrey. 'If we look at silicon, it takes almost 1500°C to grow semiconductor grade crystals, and it will fetch a very hefty electric bill for just 1kg of silicon, same as for running a kettle for over two days non-stop. And then, you would need to cut and polish those silicon boules into wafers.

'We can make single crystals in a much simpler way, entirely at room temperature with a £5 artist spray brush. With a new class of organic semiconductors based on carbon atoms, we can spray-coat organic inks onto anything, and get more or less the right size of crystals for our devices right away.'

Grigorios Rigas, a Surrey-NPL PhD student, continued: 'The trick is to cover the surface with a non-solvent so that semiconductor molecules float on top and self-assemble into highly-ordered crystals. We can also beat silicon by using light-emitting molecules to make lasers, for example – something you can't do with traditional silicon. This molecular crystals growth method opens amazing capabilities for printable organic electronics.'

# KNOWLEDGE IS POWER

Massive power density in the smallest packages

Microchip Technology now offers an integrated switching power module designed specifically for height-constrained telecom, industrial and solid-state drive (SSD) applications. These products come in an impressive thermally-enhanced package that incorporates inductors and passive components into a single, molded power converter. The slim packages simplifies board design, saves space and eliminates concern over passive components that may introduce unexpected electromagnetic interference (EMI).

**Highlights**

- Variety of module package offerings (small to large, fit to application)
- High power density with integrated magnetic and passive components
- Performance (efficiency, thermal, transient response)
- Reliable (power and thermal stress tested)
- Low EMI (CISPR 22 Class B ratings on modules)

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# Visible light reveals dark secrets

**Mark Nelson**

**We're back on the 'whatever happened to so-and-so?' kick, asking what's happening with Li-Fi. Read on to discover how Philips is still 'simply years ahead' – in a highly ethical way – and that some engineers are even doing it in the dark.**

LAST MONTH, WE FOCUSSED ON technologies that seemed to have gone off the boil (but were in fact bubbling away happily in specialised niche market applications). One 'disruptive' technology innovation that you might think had slipped off the radar screen is visible-light communication (VLC), which uses visible light instead of radio frequencies to enable high-speed wirefree data communication and Internet access. It's fairest to call this a slow burner rather than a damp squib, because VLC is still widely perceived as a technology set to shift business models, creating opportunities ripe for exploitation, totally on track to become a $113bn industry by 2022.

## Practical

Conceived at Edinburgh University by Prof Harald Haas, who coined the term Li-Fi, visible-light communication is a technology that delivers high-speed, bidirectional networked data communications to portable devices far more effectively than the better known Wi-Fi manages using radio frequency (RF) signals to transmit data.

Li-Fi has many practical advantages over Wi-Fi. For a start, Wi-Fi transmissions are constrained by the number of allocated radio frequencies, which are operating close to full capacity in many areas. Li-Fi, on the other hand, has almost no limitations on capacity because it operates using visible light, which offers 10,000 times more bandwidth than the entire radio frequency spectrum. Data is transmitted from LED light fittings by modulating the intensity of the light they give off, much faster than can be noticed or detected by the human eye. This data is received by photosensitive detectors fitted to computers, smartphones and suchlike, in which the light signal is demodulated into electronic form and processed for the specific purpose required.

## Going commercial

Technically speaking, Li-Fi is one category of visible-light communication, which in turn is a subset of optical wireless communications (OWC). However, OWC also includes infrared and ultra-violet communications as well as visible light. What makes VLC in general, and Li-Fi in particular, unique is that the same visible light energy used for illumination can also be used for communication.

Commercial exploitation is admittedly still at an early stage. In 2014, Haas established a commercial organisation called pureLiFi to exploit his university's intellectual property and this body is now working with a range of technology partners and manufacturers to develop and deliver innovative and cost-effective high-speed data communication solutions that can be integrated within existing LED lighting infrastructures.

Although pureLiFi has caught the imagination of the British media, it's by no means the only game in town. Commercial development is also underway in Europe, the Americas, China and Russia, where an entry-level Li-Fi local network called BeamCaster is on sale. Speed of installation is a key factor, according to its developers. 'All you have to do is install the transmission module on the ceiling, configure it toward the receiving devices on the work computers, and you'll get a working network in the office in just a couple hours that can quickly be disassembled if necessary,' asserts Dariush Zayents from the RiT organisation that developed the BeamCaster technology. 'As you know, it's very easy to intercept a Wi-Fi signal,' he continues. 'It passes through walls, and hackers can easily connect to a corporate network. Our device transfers data only in a light beam, so it's impossible to intercept it or eavesdrop on it.' Because radio signals are not used, there is also no interference with electronic devices and the light beam is not affected by electromagnetic fields.

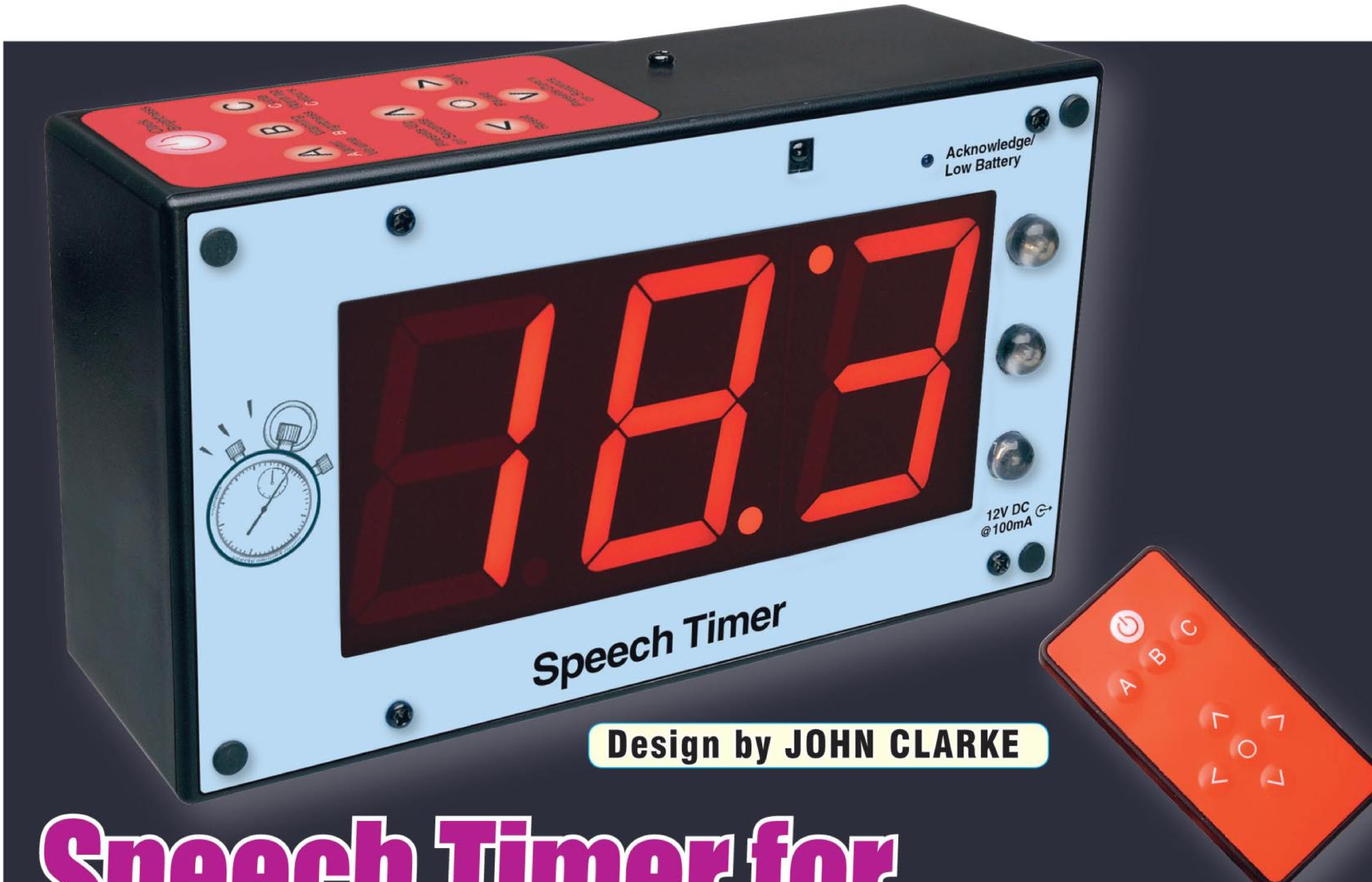
## They've got you in their sights

The Philips lighting company (remember, 'simply years ahead'!) has proved this slogan by developing a VLC system for shoppers in large stores. Since VLC is embedded directly in special LED luminaires (light fittings), it requires no additional installation, maintenance, or power. The luminaires provide all of the benefits of LED-based illumination, including dramatic energy savings over conventional lighting systems, while also providing the infrastructure for delivering indoor location-based services. The Philips indoor positioning system comes with iOS and Android cloud services that retailers (or their application developers) can use to embed positioning capabilities into mobile apps. Each lighting fixture sends its own unique identifier to shoppers' smartphones (if they agree to download the app), allowing the system to accurately pinpoint the shopper's location in the store. User privacy is respected and no personal data is requested, gathered, or stored. Mobile device locations are logged anonymously and the system stores no link to user IDs or names.

## Dark secret revealed

Fundamental to all current VLC designs is the need for LED lights emitting bright illumination. This is blindingly obvious, but what if this is not what you wanted? You don't need indoor lighting on a sunny day, nor do you want the energy cost of unnecessary lighting. That's the basic weakness that three researchers at Dartmouth College (Hanover, New Hampshire in the US) have tackled successfully. Using low-cost, off-the-shelf LEDs and photodiodes, they have come up with a new technique they call 'DarkLight' that makes light-based communication feasible with LEDs emitting extremely little light. The basis of this highly ingenious scheme is encoding data as ultra-short, imperceptible light pulses using LEDs that to the human eye are indistinguishable from LEDs in the 'off' state.

The technical details can be found in their research paper 'The DarkLight Rises: Visible Light Communication in the Dark', which you can find on the Web by Googling its title. In its current implementation, DarkLight achieves a data rate of more than 1kbit/s over link distances of nearly six feet (1.8 metres), which may sound like small beer but nevertheless pushes the limits of existing VLC techniques. The team is working hard now to boost the data rate and range by exploring higher-end LEDs and photodiodes to determine DarkLight's ultimate limit.



Design by JOHN CLARKE

# Speech Timer for Contests & Debates

**If you are involved in school or university debating contests or in Toastmasters International, you will be aware of the importance of a speech timer. It keeps meetings and events on time and even prevents individual speakers from droning on past their allotted time! The timer presented here has a large 3-digit display plus three large LEDs and a buzzer. It even has a tiny infrared remote control.**

THE INITIAL impetus for this *Speech Timer* project came from a member of Toastmasters International who was concerned at the primitive timer employed at his club. Could we design a timer which met Toastmasters International rules but did not involve an olde-worlde mechanical timer and three crudely switched coloured lights?

Well, of course we could! Mind you, Toastmasters rules do not make any mention of 3-digit LED 7-segment displays – those rules were drawn up over 80 years ago when carbon-zinc batteries and incandescent lamps were state-of-the-art technology! Microcontrollers, light-emitting diodes and infrared remote controls would have been unimaginable!

So our *Speech Timer* provides the basic green, amber and red warning lights, plus a manually-operated final alarm, as required for speeches defined by Toastmasters' rules. It also provides a 3-digit up/down timer, all controlled by a cheap microcontroller.

Specifically, we have incorporated preset time periods that match Toastmasters International rules for various speech lengths. Table 1 shows the details.

These time periods are based on the *July 2015 to June 2016 Speech Contest Rule Book*. By the way, there are apps and software to time speeches at Toastmasters' meetings but these are not

## Features and specifications

### Features

- Battery and/or DC plugpack operation
- Readout on large 7-segment displays
- Visual warnings via green, amber and red indicator lights
- Audible warning buzzer (manually-operated)
- Optional automatic visual warning operation
- Manual visual and buzzer warning control
- Dimming of main display and warning lights
- Volume adjustment for audible warning signal
- Low-battery indicator
- 99-minute maximum time period
- Preset Toastmasters' contests and other presets included
- Minutes and tens-of-seconds display (seconds display accessible)
- Infrared remote control operation
- Reset, pause and start timer controls
- Blue acknowledge LED for IR signalling
- Separate duplicated warning lights for timekeeper and speaker

### Specifications

- Power: 12V DC @ 100mA
- Current drain: 76mA typical at full brightness; up to 100mA with warning LED and Alarm on
- Audible alarm: 1.22kHz tone modulated at 200Hz
- Display multiplexing: 100Hz
- Low battery indication: warning turns on below 8.8V and off above 8.92V (voltage sampled at 3.3-second intervals)
- Latency: ~18ms from press of IR remote button to timer response

really useful when they must be seen by a room (or even a hall) full of people.

Naturally, the *Speech Timer* can also be used to time speakers in debating contests and meetings. In fact, it can be used anywhere a highly-visible digital timer is required. By default, it counts up but it can also be made to count down (see panel later in the article).

### Presentation

The *Speech Timer* is housed in a plastic case with the 3-digit 7-segment LED display on the front. Down the right-hand side are the three large LEDs, arranged like traffic lights, with red at the top, amber in the middle and green at the bottom of the stack. These are duplicated on the rear of the case, together with the small loudspeaker which provides the ending buzzer.

The *Speech Timer* can be placed in the room so that the audience and the speech timer can see the 3-digit display, while the speaker can only see the green/amber/red LEDs when they are lit.

The *Speech Timer* can be run from an internal battery (eight AA alkaline cells) or from a 12V DC plugpack. You can also use NiMH or Nicad cells instead of alkalines, and these can be trickle charged via the 12V plugpack.

### Remote control

Apart from an on/off switch mounted near the socket for the DC plugpack, there are no controls on the unit. Instead, all functions are set by a tiny remote control, made by SparkFun – the same unit as used in our *9-Channel Remote Control* in the December 2016 issue.

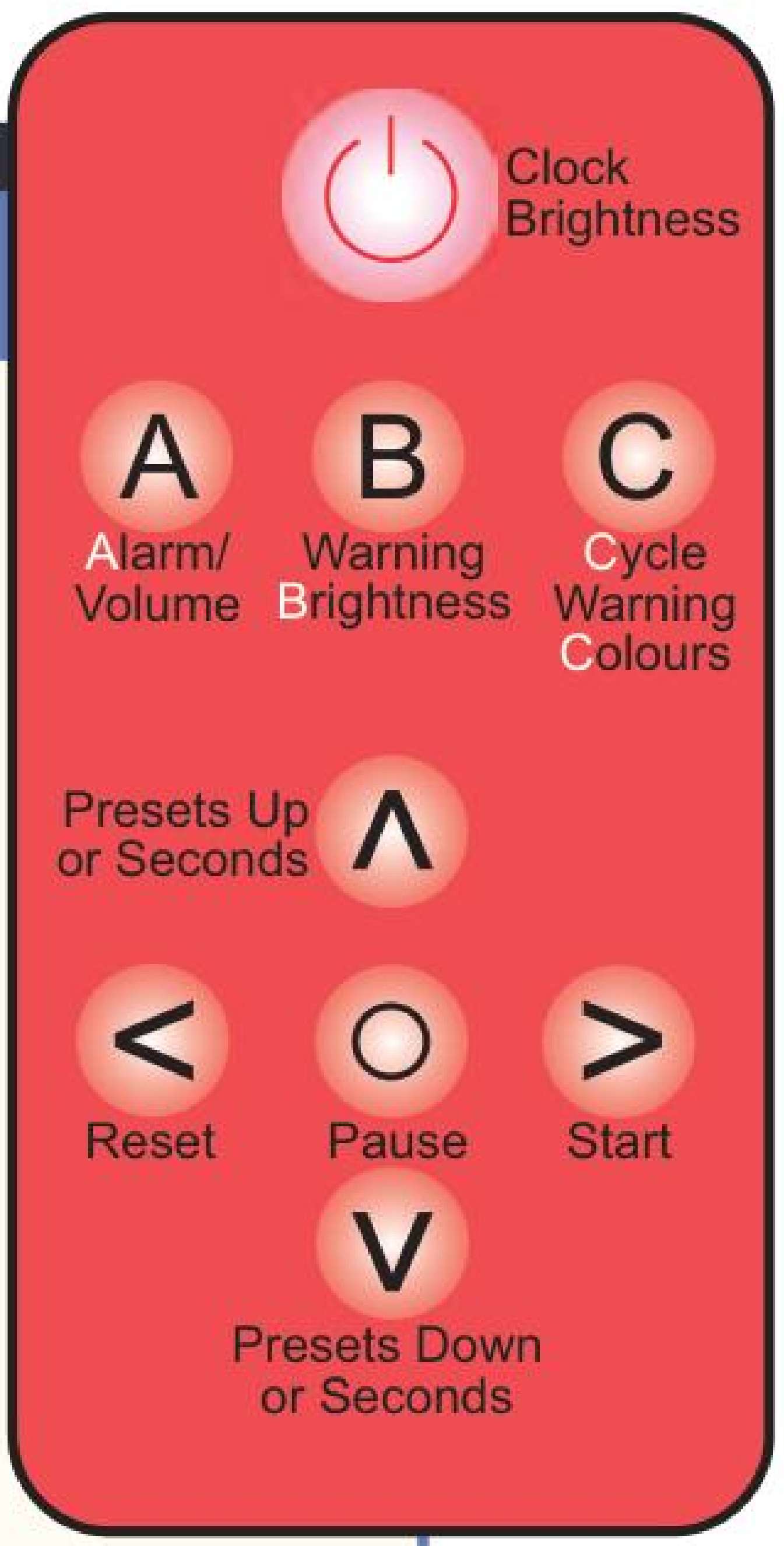


**Fig.1: this artwork is attached to the top of the case and shows the button assignments on the remote control.**

This remote measures just 80 × 40 × 7mm and is powered by a CR2025 3V cell. It has nine pushbuttons or more correctly, small snap-action domes. The buttons are Power (shown as a circle logo with a stroke through the top), A, B and C and a 5-button array.

We have assigned the buttons as shown in Fig.1. The power button is used for controlling the display brightness, while buttons A, B and C are the warning indication controls: A for manually sound the **A**larm, B for the warning LED **B**rightness and C for manually **C**ycling through the warning LEDs. The functions of the 5-button array are described later in this article.

A tiny blue LED on the *Speech Timer's* front panel flashes to acknowledge signals from the infrared remote control, and it doubles as a low-battery indicator, staying lit when the battery voltage is low.

### Circuit description

Fig.2 shows the complete circuit of the *Speech Timer*. It's based on a PIC16F88 microcontroller (IC1) and this drives the 3-digit 7-segment LED display and warning LEDs (via transistors Q1-Q8 and IC2 and IC3). IC1 also monitors the output from the infrared receiver (IRD1) and the supply voltage.

Each of the LED display segments comprises four series-connected LEDs, evenly spaced apart and there are two series-connected LEDs for the decimal point. When a segment is lit, it will typically have 7-8V across the four series-connected LEDs.

That presents a design problem beause IC1 requires a 5V supply, while the displays need to be driven from a supply voltage of 12V. We solved that conundrum by tying IC1's positive (Vdd) supply rail to the +12V supply rail, while its negative rail is supplied from a 7905 3-terminal regulator.

The segment anode lines of the 3-digit display are driven by PNP transistors Q1-Q8 (for the seven segments plus the decimal points). The emitter of each transistor is connected to the +12V supply and the collector is connected to the segment anode via an 82Ω current-limiting resistor or via a 180Ω resistor for the DP (decimal point). Each segment line is driven when the base

### Table 1: Preset and manual time periods (counting up)

| Type | Length (minutes) (display when unit reset) | Green warning (elapsed minutes) | Amber warning (minutes or minutes:seconds) | Red warning (elapsed minutes) | Disqualification minimum period (minutes:seconds) | Disqualification maximum period (minutes:seconds) |
|---|---|---|---|---|---|---|
| Any (manually operated) | 0:0 | when selected | when selected | when selected | | |
| Table Topics* | 1-2 | 1 | 1:30 | 2 | 1:00 | 2:30 |
| Evaluation* | 2-3 | 2 | 2:30 | 3 | 1:30 | 3:30 |
| Tall Tales* | 3-5 | 3 | 4 | 5 | 2:30 | 5:30 |
| International and humorous* | 5-7 | 5 | 6 | 7 | 4:30 | 7:30 |
| Speech1 | 10' | 7 | 9 | 10 | | |
| Speech2 | 15' | 10 | 13 | 15 | | |
| Speech3 | 20' | 15 | 18 | 20 | | |
| Speech4 | 30' | 20 | 25 | 30 | * Denotes Toastmasters contests.<br>' is the symbol for minutes | |
| Speech5 | 40' | 30 | 35 | 40 | | |
| Speech6 | 50' | 40 | 45 | 50 | | |
| Speech7 | 60' | 50 | 55 | 60 | | |
| Speech8 | 70' | 60 | 65 | 70 | | |
| Speech9 | 80' | 70 | 75 | 80 | | |
| Speech10 | 90' | 80 | 85 | 90 | | |

of its transistor is pulled low by the respective output of IC1. When the base is taken high (ie, +12V), the transistor is switched off and the segments are off.

As shown on the circuit, outputs RA3, RA4, RB1, RB2, RB4, RA0, RB7 and RA2 of IC1 connect to the bases of transistors Q1-Q8 via 470Ω resistors.

The three common-cathode 7-segment displays are multiplexed. This means that the seven anode segments and the decimal points of the digits are driven by the eight transistors and then each digit is turned on for about one-third of the time by pulling its common cathode low.

For a digit to light, its common cathode needs to be connected to the 0V line of the 12V supply. But we can't directly do this via any of IC1's outputs since IC1's negative rail (GND) is only 5V below the +12V supply rail. So the circuit needs level shifting from the negative rail of IC1 to 0V.

IC2 and IC3 take care of this level-shifting requirement and drive the common-cathode connections at the same time. IC2 is a 4051 analogue single-pole 8-way switch that's used as a single-pole 4-way switch. IC2 can connect its common-pole contact 'Z' at pin 3 to one of the Y0, Y1, Y2 and Y3 terminals. Which connection is made depends on the logic level at the A0 and A1 inputs and that is under the control of IC1.

IC2 has separate supply rails for the control inputs (Vss) and for its output switching (Vee). Vss, pin 8, is connected to ground, the negative supply line for IC1, while Vee is tied to the 0V rail. So IC2 does the signal level shifting.

The A0 and A1 inputs of IC2 are driven from the RB6 and RB5 outputs of IC1 respectively. When both inputs are low, the Y0 output of IC2 connects to the Z-pole contact of IC2 and is pulled high via a 4.7kΩ resistor. This output then drives the 4B input of IC3.

IC3 is a ULN2003 7-Darlington transistor open-collector driver. We use four of these Darlingtons to separately drive the common cathodes of the 7-segment displays and the common cathodes of 'traffic light' LEDs 1-6 and the acknowledge/low battery indicator LED (LED7). When 4B is driven, the 4C collector (pin 13) connects the common of display DISP1 to 0V, so that digit lights up.

Other combinations of the A1 and A2 inputs select the Darlington transistors at IN5, IN2 and IN3. For example, when A1 and A2 are both high, IC2's Y3 output drives 5B of IC3. IC3's 5C collector then connects the common of DISP2 to 0V and the second digit lights up, and so on.

We drive DISP1 for 2.5ms, then DISP2, DISP3 and then the LEDs, all for the same 2.5ms period.

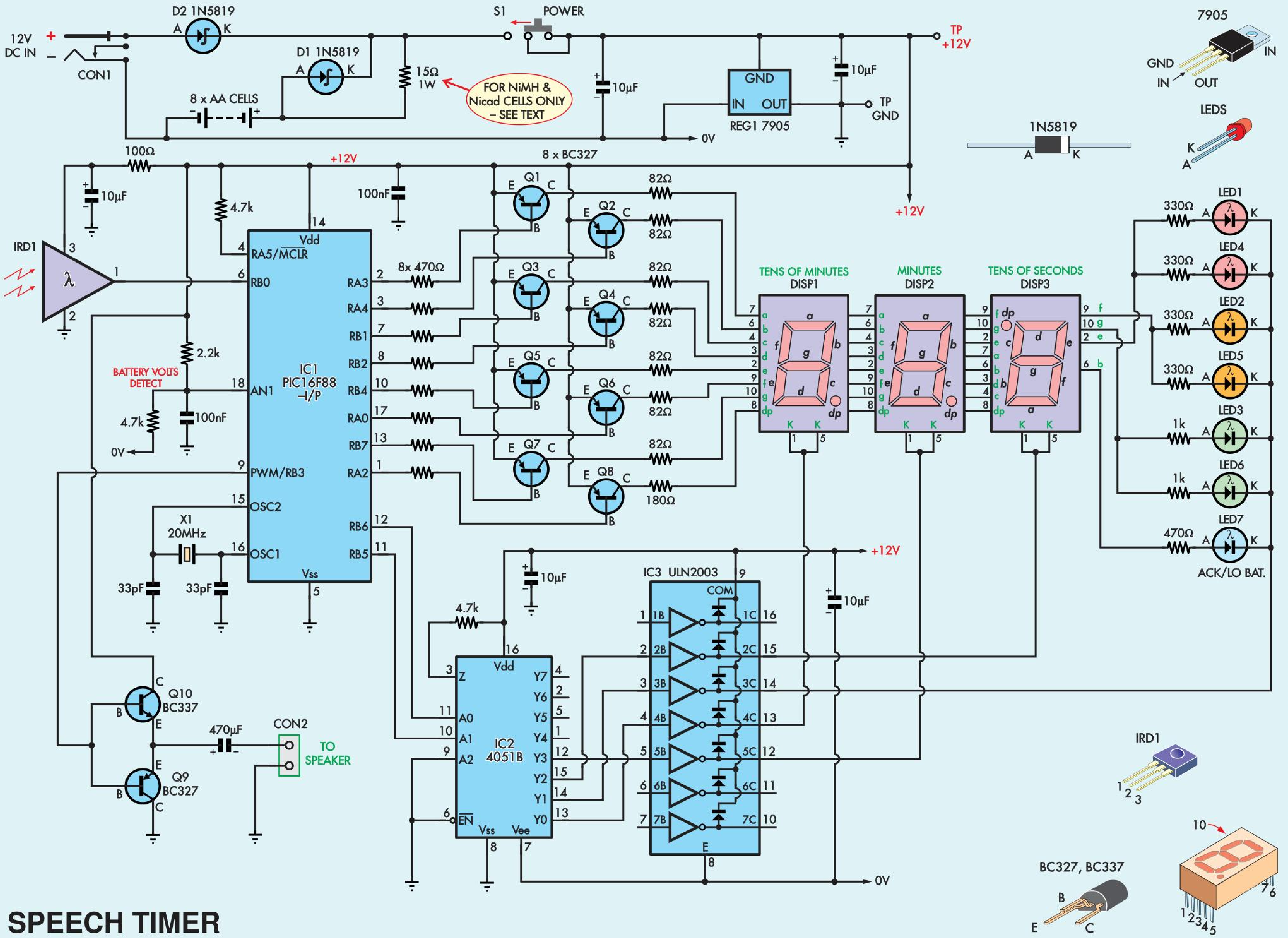
### Flashing colon display

Note that the connections to DISP3 are mixed up compared to the connections to DISP1 and DISP2. For example, the 'A' segment for DISP1 is connected to the 'A' segment of DISP2, but this connects to the 'F' segment of DISP3. The reason for that is partly due to the fact that DISP3 is actually mounted upside down compared to the others, so that we can have a flashing colon between DISP2 and DISP3.

Also, the connections to DISP3 have been done in this way to make the PCB pattern practical. Which segments are driven for each display is sorted out in the software for IC1, so the different connections for DISP3 do not matter.

Several different resistor values are used for driving the displays and LEDs. We use 82Ω for the segments but the decimal points for DISP1-DISP3 use a 180Ω resistor. This is because the decimal points have only two LEDs, compared to four in the segments.

A similar comment applies to the indicator LEDs, where the resistor values are selected to produce a similar brightness to the 7-segment displays. For the red and amber LEDs, 330Ω resistors are used. The green LEDs are much brighter for the same current and so the current in these is further reduced using 1kΩ resistors. A 470Ω current-limiting resistor is used for blue LED7. Dimming is achieved by


12V DC IN
CON1
D2 1N5819
D1 1N5819
8 x AA CELLS
15Ω 1W
FOR NiMH & Nicad CELLS ONLY – SEE TEXT
S1 POWER
10µF
REG1 7905
GND IN OUT
TP +12V
TP GND
0V
100Ω
+12V
8 x BC327
100nF
4.7k
IRD1
IC1 PIC16F88 –I/P
Vdd
RA5/MCLR
RB0
AN1
PWM/RB3
OSC2
OSC1
Vss
RA3
RA4
RB1
RB2
RB4
RA0
RB7
RA2
RB6
RB5
8x 470Ω
2.2k
BATTERY VOLTS DETECT
X1 20MHz
33pF
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
82Ω
180Ω
TENS OF MINUTES DISP1
MINUTES DISP2
TENS OF SECONDS DISP3
330Ω
1k
470Ω
LED1
LED4
LED2
LED5
LED3
LED6
LED7
ACK/LO BAT.
IC3 ULN2003
COM
IC2 4051B
Z
A0
A1
A2
EN
Vee
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
Q10 BC337
Q9 BC327
470µF
CON2
TO SPEAKER
7905
LEDS
1N5819
BC327, BC337
B E C
A K

## SPEECH TIMER

**Fig.2: the *Speech Timer* circuit is based on a PIC16F88 microcontroller (IC1). This drives a 3-digit 7-segment LED display, six warning LEDs (LED1-6) and a blue acknowledge LED (LED7) via transistors Q1-Q8 and IC2 and IC3. IC1 also monitors the output from the infrared receiver (IRD1) and the supply voltage.**

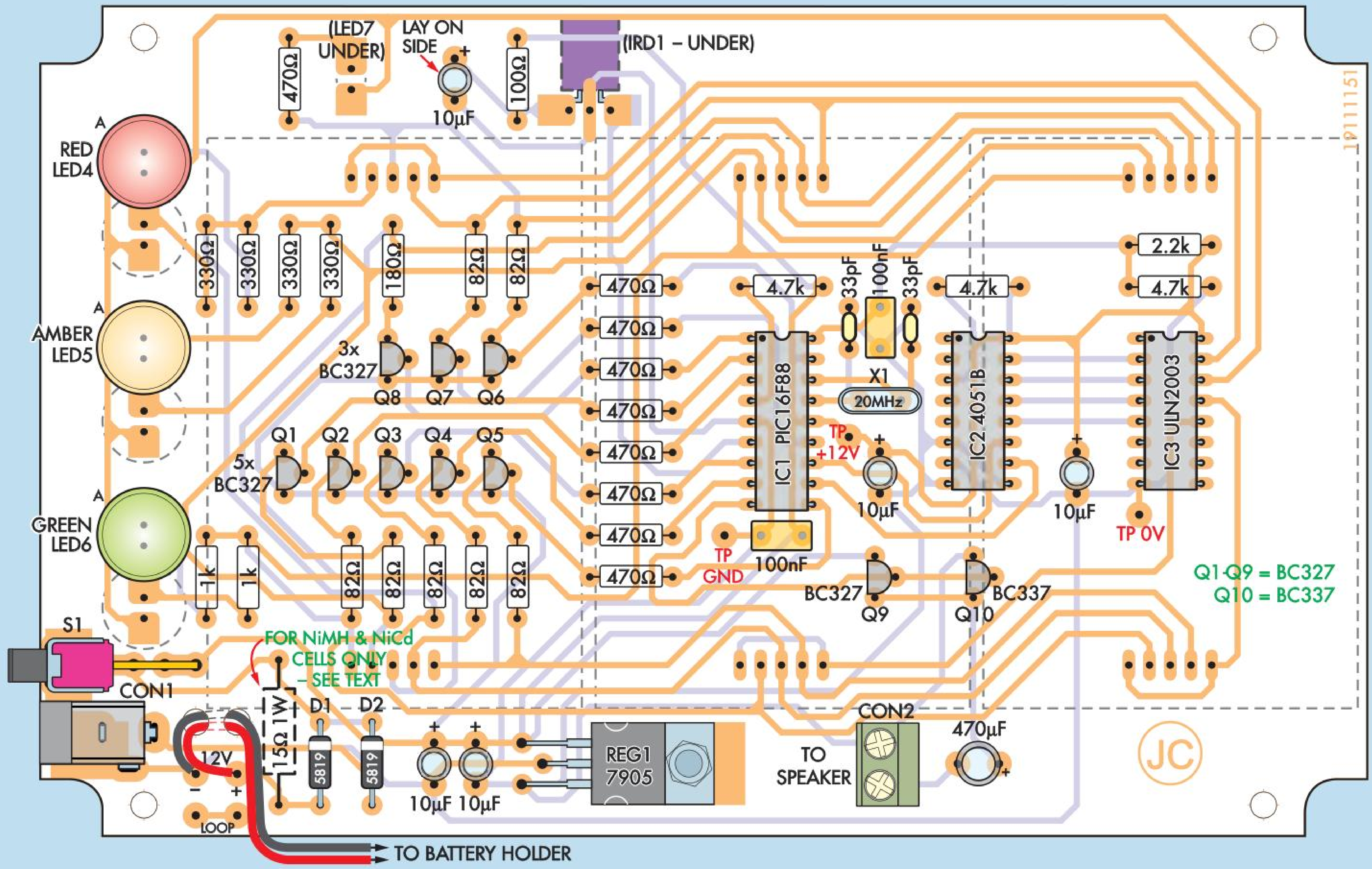
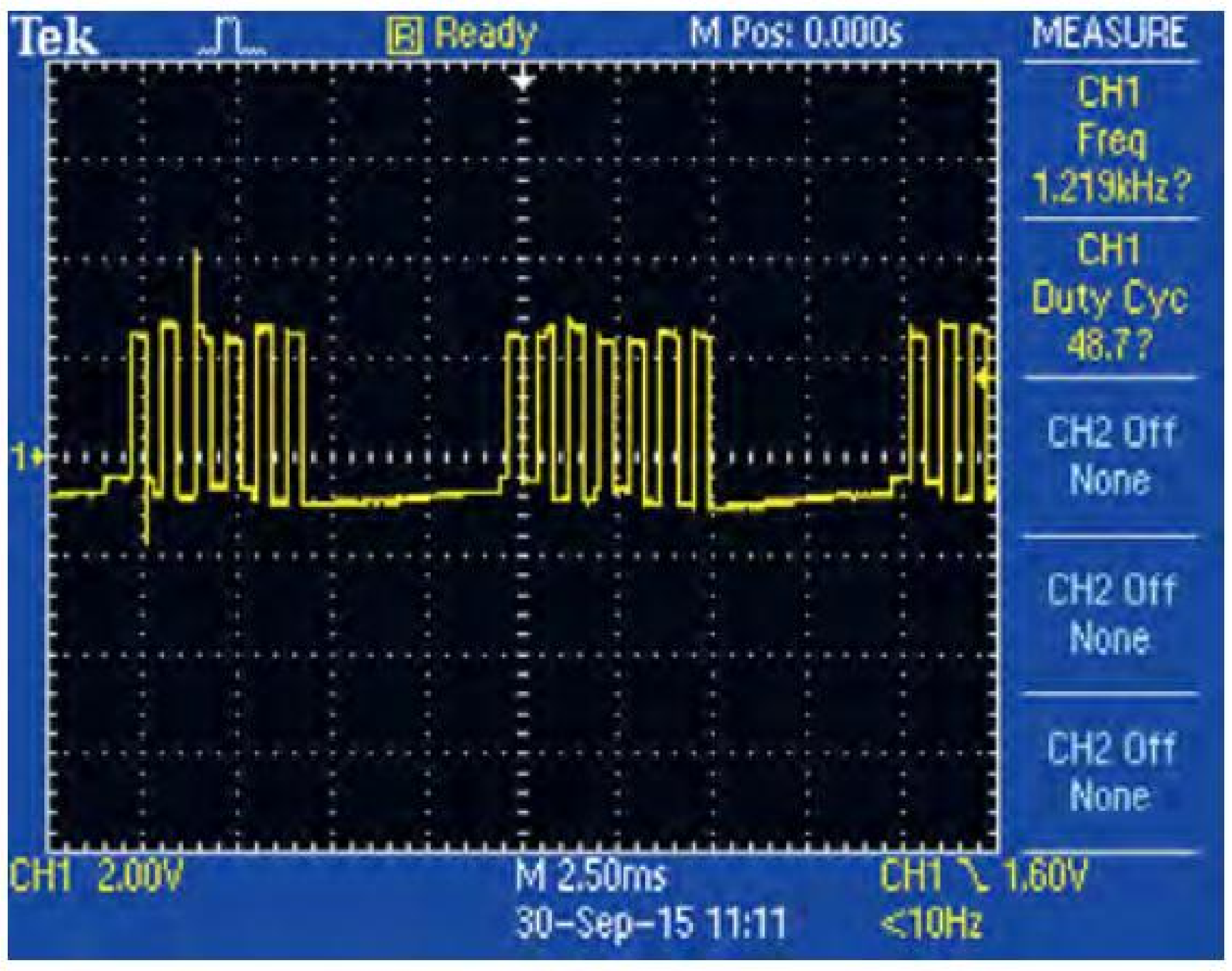

(LED7 UNDER)
LAY ON SIDE
(IRD1 – UNDER)
470Ω
100Ω
10µF
RED LED4
AMBER LED5
GREEN LED6
A
330Ω
180Ω
82Ω
3x BC327
Q8 Q7 Q6
Q1 Q2 Q3 Q4 Q5
5x BC327
470Ω
4.7k
33pF
100nF
X1
20MHz
IC1 PIC16F88
TP +12V
IC2 4051B
IC3 ULN2003
2.2k
TP 0V
TP GND
BC327
Q9
BC337
Q10
Q1-Q9 = BC327
Q10 = BC337
1k
S1
CON1
FOR NiMH & NiCd CELLS ONLY – SEE TEXT
15Ω 1W
D1 D2
5819
12V
LOOP
REG1 7905
10µF 10µF
CON2
TO SPEAKER
470µF
TO BATTERY HOLDER
11111151
JC

**Fig.3: follow this diagram to install the parts on the rear of the PCB. Note that PC stakes are installed at the three test points (TP) and at the LED4-LED6 positions. LED4-6 are then mounted proud of the PCB, as described in the text.**

switching the displays off for part of the normal 2.5ms on period.

### Infrared receiver

Infrared receiver IRD1 receives the signal sent by the SparkFun remote. A unique code is transmitted from the remote for each separate pushbutton and the infrared signal is sent as 38kHz bursts, using coding that is known as 'Pulse Distance Protocol'. For further information about the infrared coding, refer to the *9-Channel Infrared Remote Control* article in the December 2016 issue.


Tek
Ready
M Pos: 0.000s
MEASURE
CH1 Freq 1.219kHz?
CH1 Duty Cyc 48.7?
CH2 Off None
CH2 Off None
CH2 Off None
1
CH1 2.00V
M 2.50ms
CH1 ⁀ 1.60V
30-Sep-15 11:11
<10Hz

**This oscilloscope grab shows the modulated 1.22kHz signal across the loudspeaker when the alarm is sounding at full volume.**

IRD1 includes an amplifier and a demodulator. Demodulation removes the 38kHz component and IRD1's pin 1 output goes low when it is receiving the pulsed 38kHz signal and high in the absence of signal.

IC1 decodes the incoming signal from IRD1 and reacts to any valid coded signal. So, for example, when the 'A' button is pressed on the remote control, the speaker will be driven. This alarm signal comprises a 1.22kHz signal modulated at 200Hz.

This 1.22kHz signal is produced by a PWM (pulse-width modulated) output at pin 9 of IC1. The signal is buffered using complementary transistors Q9 and Q10, AC-coupled to the loudspeaker via a 470µF capacitor. The volume is set by the actual pulse width of the signal, with a 50% duty cycle giving maximum volume.

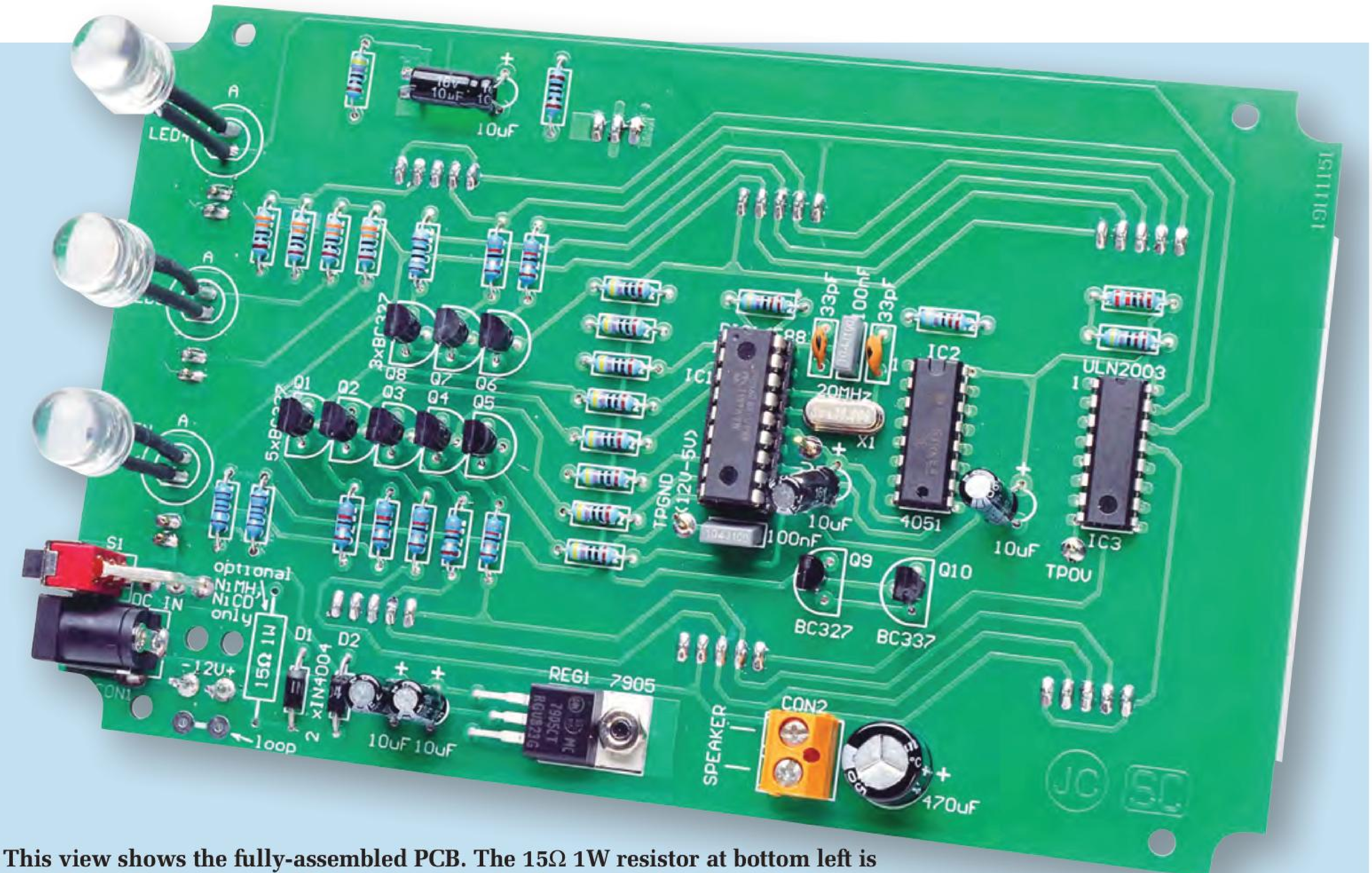
The accompanying scope waveform shows the signal across the loudspeaker when sounding an alarm at maximum volume. The alarm signal comprises six or seven cycles of the 1.22kHz tone modulated on and off at a 5ms rate.

### Clock signal

IC1 runs at 20MHz using crystal X1, to ensure timekeeping accuracy. 20MHz is used in preference to a lower frequency such as 4MHz, as the software requires considerable processing to drive the displays, update the timer and decode the infrared signal without faltering.

The battery voltage is monitored at analogue input AN1 (pin 18) of IC1, via a 2.2kΩ and 4.7kΩ resistive divider. IC1 converts the monitored battery voltage to a digital value and compares this against the low-battery voltage threshold of 8.8V. If the battery voltage is low, it turns on LED7 continuously, at a low level. LED7 also flashes when IC1 receives a valid signal from the remote control.

As previously noted, the circuit can be run from a 12V DC plugpack and/or a battery comprising eight AA cells. They are connected to power switch S1 via Schottky diodes D1 and D2. These diodes provide reverse-polarity protection and isolate the 12V plugpack supply from the AA cells. D2 could be a standard 1N4004 instead, but a Schottky diode is specified to avoid any mix up when installing D1 and D2.


LED1
A
10uF
1911151
3xBC327
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
5xBC337
IC1
IC2
IC3
33pF
100nF
20MHz
X1
ULN2003
4051
TPGND
TP0V
100nF
Q9
Q10
BC327
BC337
S1
optional NiMH NiCD only
DC IN
CON1
15Ω 1W
D1
D2
2 x1N4004
-12V+
loop
REG1 7905
10uF 10uF
CON2
SPEAKER
470uF
JC
SC

This view shows the fully-assembled PCB. The 15Ω 1W resistor at bottom left is installed only if rechargeable NiMH or Nicad cells are fitted to the unit. Be sure to leave this resistor out if you intend using alkaline cells.

A 15Ω 1W resistor can be fitted between the battery and the 12V supply following D2 to allow trickle charging of rechargeable NiMH or Nicad cells. This resistor must be omitted if alkaline cells are used.

REG1 is a 7905 negative regulator that provides the 5V supply to IC1. As shown, 10μF supply decoupling capacitors are included at the input and output of this regulator, while the supply to IC1 (pin 14) is further decoupled with a 100nF capacitor.

## Building it

Building the *Speech Timer* is easy since all the parts are mounted on a double-sided PCB coded 19111151 (162.5 × 102mm), which is available from the *EPE PCB Service*. This is housed in a UB2 plastic case (197 × 113 × 63mm), with the lid replaced by a red Perspex or acrylic transparent sheet. Alternatively, a cut-out can be made in the lid that comes with the case and a transparent window fitted to this cut-out.

As shown on Figs.3 and 4, parts are mounted on both sides of the PCB. Most of the parts are mounted on the 'rear' of the PCB, while the 'front' carries the three 7-segment LED displays (DISP1-DISP3) plus five other parts, including the infrared receiver (IRD1).

Begin the *Speech Timer* assembly by installing the parts on the rear of the PCB – see Fig.3. The resistors go in first, take care to use the correct value in each location – check each one

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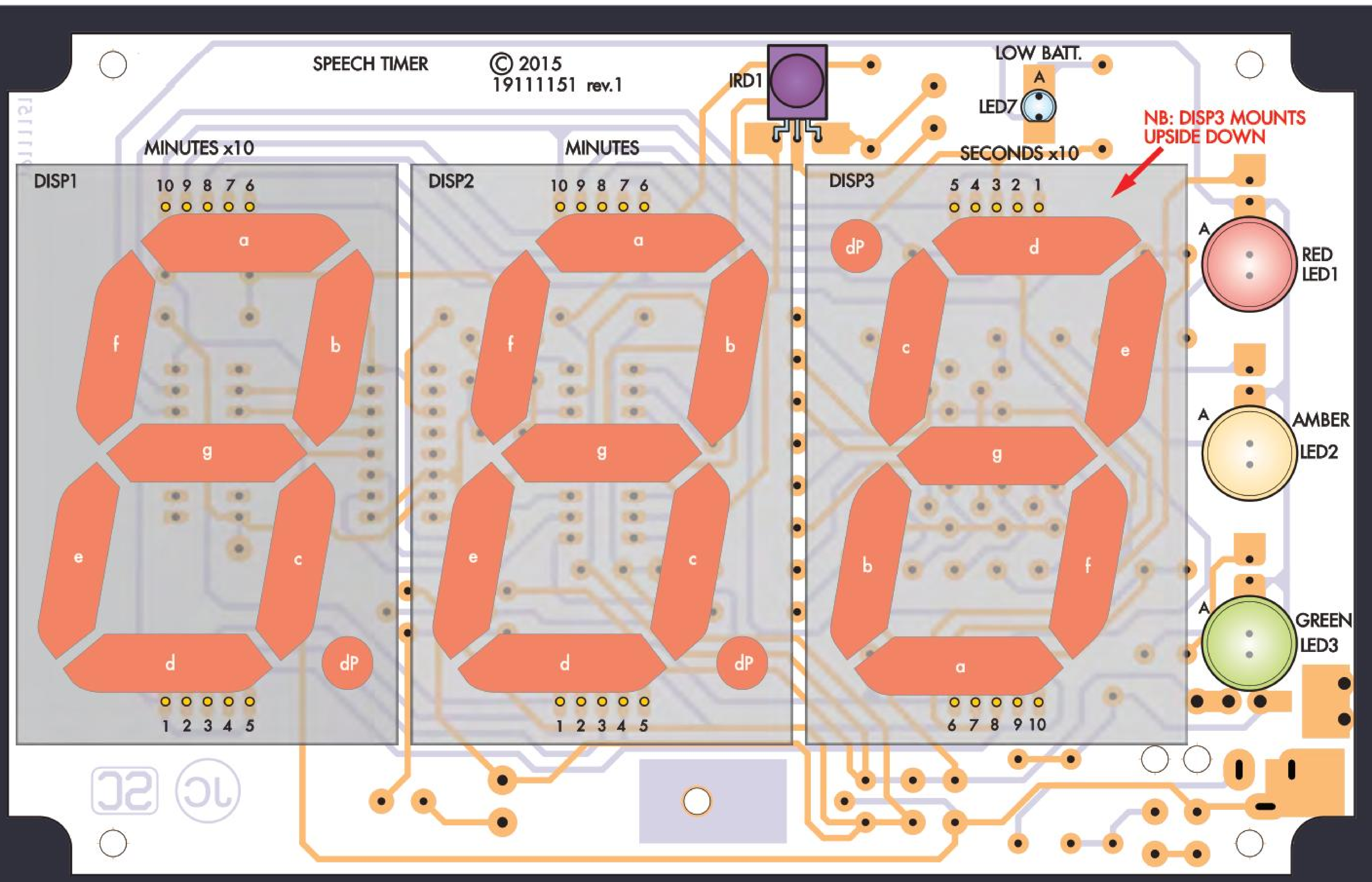

SPEECH TIMER
© 2015
19111151 rev.1
IRD1
LOW BATT.
A
LED7
NB: DISP3 MOUNTS UPSIDE DOWN
MINUTES x10
MINUTES
SECONDS x10
DISP1
DISP2
DISP3
10 9 8 7 6
5 4 3 2 1
1 2 3 4 5
6 7 8 9 10
a
b
c
d
e
f
g
dP
RED
LED1
AMBER
LED2
GREEN
LED3

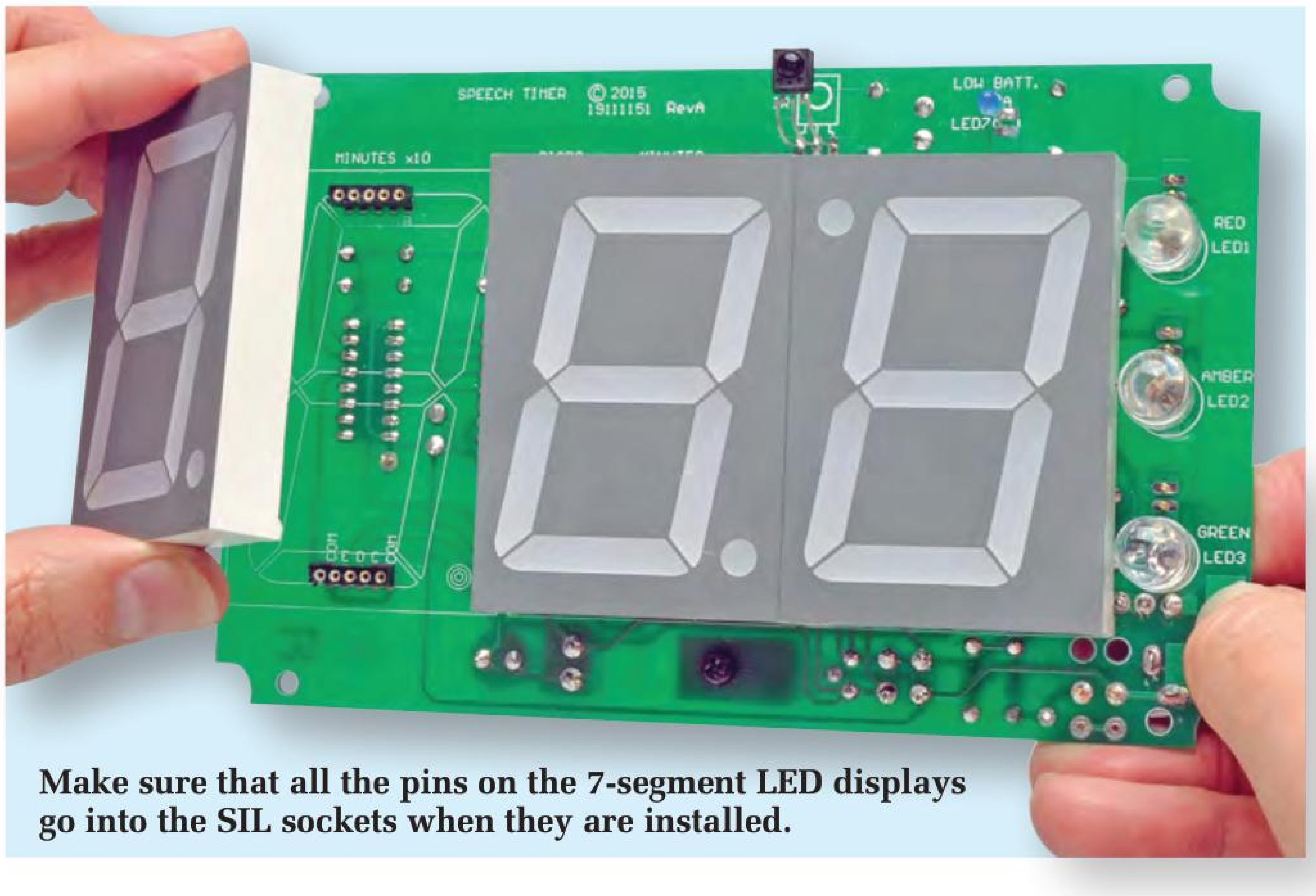
**Fig.4: here's how to install the parts on the front of the PCB. The 7-segment LED displays (DISP1-DISP3) plug into 5-way SIL socket strips and DISP3 must be installed upside down. IRD1, LED1-3 and LED7 are all mounted proud of the PCB, as described in the text (see also Figs.5 and 6).**

using a digital multimeter (DMM) before soldering it into position.

Note that the 15Ω 1W resistor is only installed if you intend to run the *Speech Timer* using NiMH or Nicad cells. DO NOT install this resistor if you will be using alkaline cells.

Diodes D1 and D2 go in next, followed by IC1's 18-pin DIL socket. Make sure that these parts are all oriented correctly before soldering them to the PCB. IC2 and IC3 can then be fitted and these parts can either be directly soldered in place or mounted via 16-pin sockets.

Regulator REG1 is next on the list. As shown, this part mounts horizontally with its leads bent down through 90° to fit into the allocated holes. Fasten the regulator's tab to the PCB using an M3 × 6mm screw and nut before soldering its leads. Don't solder the leads first – you could crack the PCB tracks or pads as the tab is fastened down if you do.


SPEECH TIMER
© 2015
19111151 RevA
LOW BATT.
LED7
MINUTES x10
RED
LED1
AMBER
LED2
GREEN
LED3

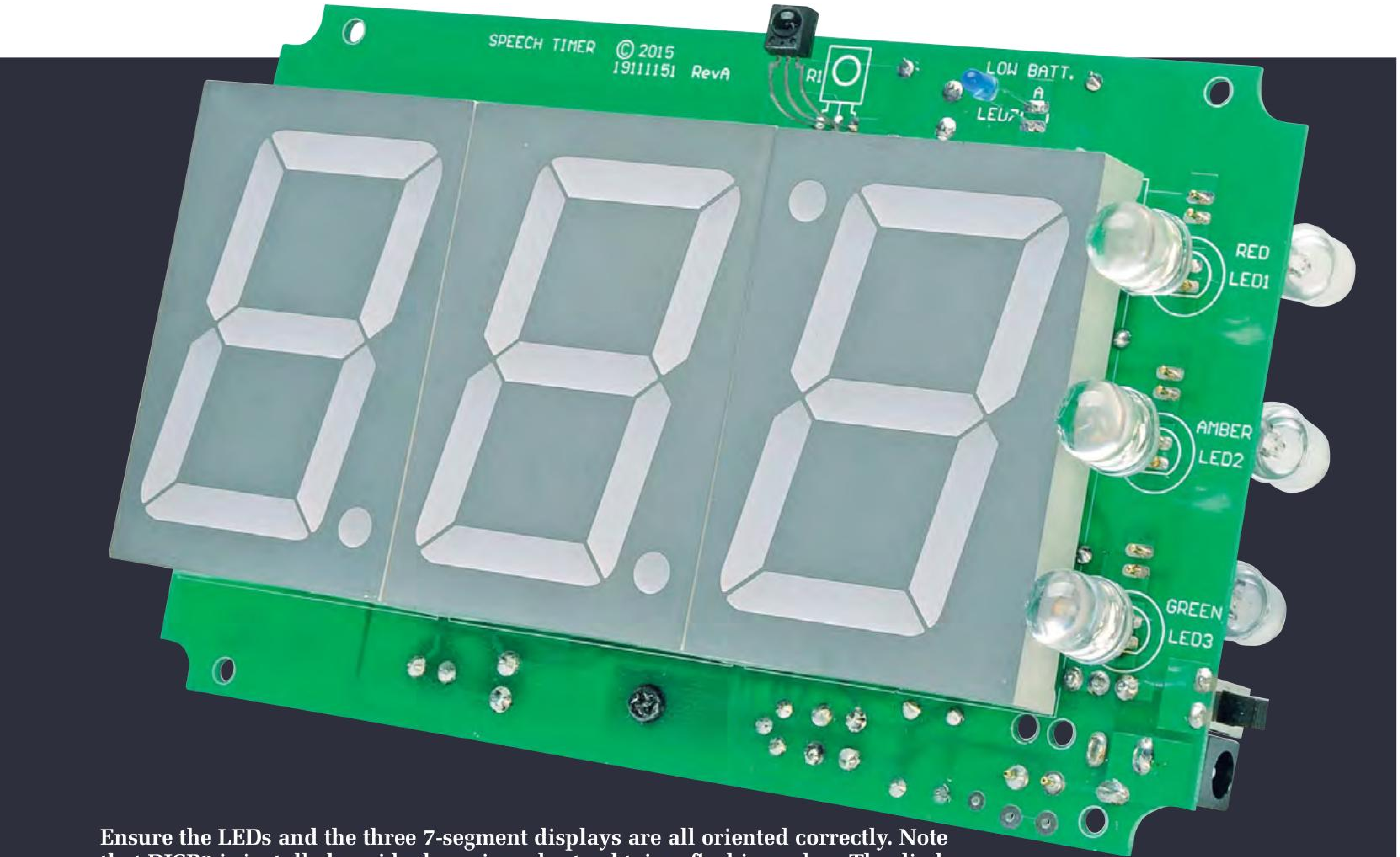
**Make sure that all the pins on the 7-segment LED displays go into the SIL sockets when they are installed.**

Crystal X1 can now be fitted; it's mounted just to the right of IC1 and can go in either way around. That done, install PC stakes at the 12V supply positions near CON1 (to connect the battery leads), at the TP 12V, TP GND and TP 0V positions and at the LED4-LED6 positions.

The next step is to mount transistors Q1-Q10. Note that Q1-Q9 are all BC327s, while Q10 is a BC337. Make sure that the BC337 goes in the Q10 location. Make sure also that the tops of the transistors sit no more than 10mm above the PCB, otherwise they will later foul the AA cells (if fitted).

Now for the capacitors. Install these as shown, making sure that the electrolytic types are correctly oriented. **Note that the 10µF electrolytic capacitor at top left must be installed with its side flat against the PCB** (see photo), so that it will later clear the AA cells.

Follow with the DC socket (CON1), the screw terminal block (CON2) and switch S1. Be sure to install CON2 with its wire entry side towards REG1.



**Ensure the LEDs and the three 7-segment displays are all oriented correctly. Note that DISP3 is installed upside down in order to obtain a flashing colon. The diode test facility on a DMM can be used to sort out the LED colours (see text).**

That completes assembly on the rear side of the PCB apart from LED4-6. Leave these off for the time being.

### Front PCB assembly

Fig.4 shows the layout on the front of the PCB. The first step is to install six 5-way SIL (single in-line) socket strips to mount the three 7-segment displays. These socket strips are cut from three 14-pin IC sockets and the cut edges filed to a smooth finish before installation. Be sure to push the socket strips all the way down so that they sit flush against the PCB before soldering their pins.

Next, cut the pins on each 7-segment display to 4mm in length using a pair of side-cutters. That's best done by first cutting a 4mm-wide length of cardboard and then holding this against the pins as they are trimmed. Don't install the displays just yet though. That's done after the remaining parts have been installed on this side of the PCB.

LED1-3 can go in first. These must all be oriented correctly, with the longer anode leads going to the 'A' position, and they must be mounted on 12mm lead lengths.

These LEDs all come with clear lenses, so you will have to sort out which is red, which is amber and which is green. That's easily done by using the diode test facility on a DMM. Each LED should light when the DMM's probes are connected with the correct polarity (ie, red to anode, black to cathode).

Use a 12mm-wide cardboard spacer to set the LED heights. It's just a matter of sliding the spacer between the leads, pushing the LED down onto the spacer and then lightly tack soldering one of the leads. The other lead can then be soldered, after which extra solder can be added to the first lead.

Once all the LEDs are in place, tin their leads from the PCB to just shy of the plastic lenses. This will stiffen the leads and ensure that the LEDs cannot be pushed in from the front panel when the PCB is installed in the case.

Alternatively, before installing the LEDs, fit their leads with 12mm lengths of 1mm-diameter heatshrink sleeving (this will also eliminate the need to cut a cardboard spacer).

LED7 is fitted in similar fashion on 13mm-long lead lengths (Fig.5). Once again, its anode lead is the longer of the two and there's a flat side on the plastic body adjacent to the cathode.

Now for the infrared receiver. Fig.6 shows how this part is mounted. First, bend its leads down through 90° exactly 5mm from its body, then fit it to the PCB on 15mm vertical lead lengths (use a 15mm-wide cardboard spacer to set this). It's a good idea to lightly tack solder one lead first, then check that all is correct before soldering the remaining two pins and then refreshing the first pin with extra solder.

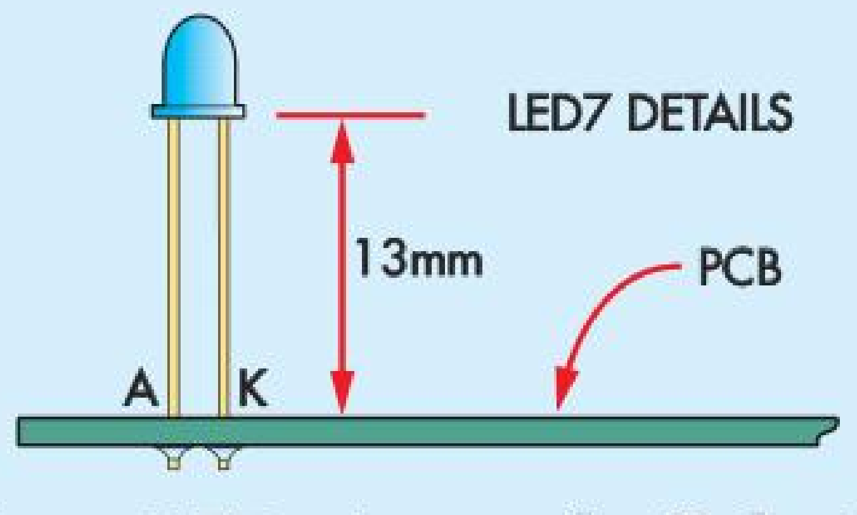


**Fig.5: LED7 is stood off the PCB on 13mm-long leads, as shown here.**

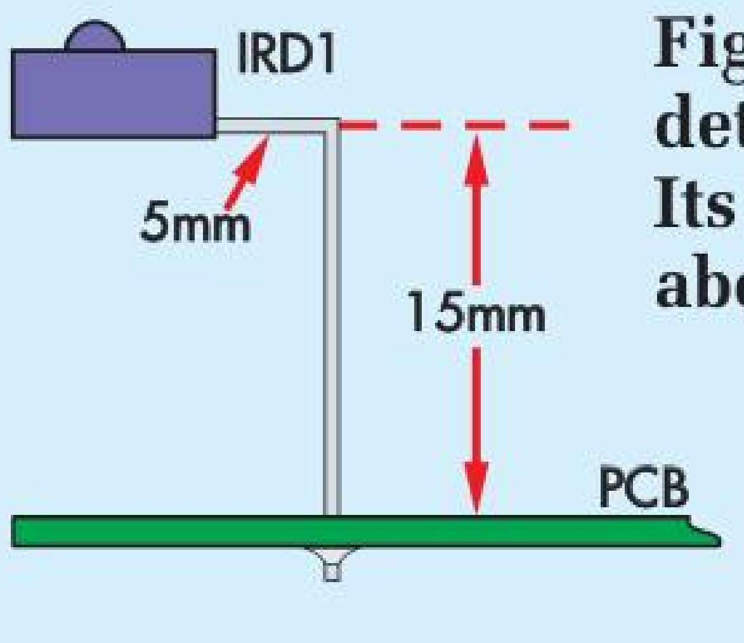
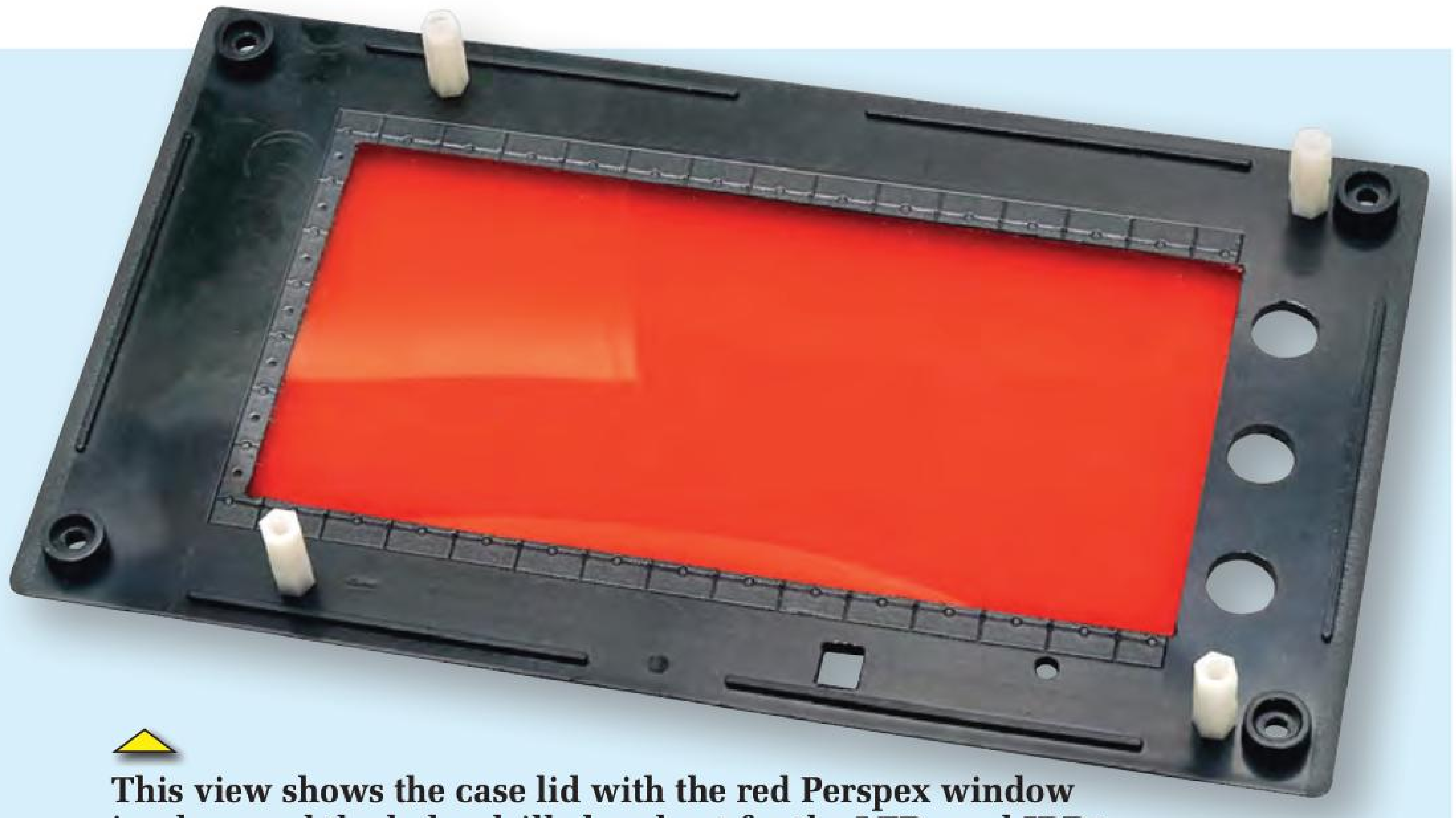


**Fig.6: the mounting details for IRD1. Its body sits 15mm above the PCB.**



This view shows the case lid with the red Perspex window in place and the holes drilled and cut for the LEDs and IRD1.

### Installing LED4-6

The PCB can now be flipped over and LED4-6 installed. These LEDs must be installed so that their plastic bodies are 34mm above the PCB and to do that, it's necessary to solder their leads to tinned copper wire risers.

First, fit 35mm lengths of 1mm-diameter tinned copper wire to the six PC stakes in the LED locations. Make sure that these wires are perfectly straight and vertical. You can straighten tinned copper wire by clamping one end in a vice and then stretching it slightly by pulling on the other end with pliers. Once the risers are in place, cut a 34mm-wide cardboard strip and use this as a guide to trim the wire lengths so that their ends are exactly 34mm above the PCB.

The next step is to cut six 25mm-lengths of 2mm-diameter heatshrink sleeving. These are then slipped over the risers and the PC stakes, leaving bared 9mm-long wire ends at the top.

The final step is to install the LEDs. As before, you will first have to use the diode test facility on a DMM to sort out the colours. That done, install LED4 by first feeding its leads down the heatshrink tubing. Push it all the way down until its body contacts the tops of the risers, then solder each lead to its riser between the heatshrink and the LED's body. Repeat this procedure for LED5 and LED6, taking care to ensure that the LEDs are correctly oriented.

Finally, complete the PCB assembly by plugging in the three 7-segment displays (DISP1-DISP3). There's just one thing to watch out for here: **DISP3 must be fitted upside down, so that its decimal point is at top left (see Fig.4).** As explained earlier, that's done to obtain a flashing colon between DISP2 and DISP3.

Note that the top surfaces of the displays should be 15mm above the PCB when they are installed. Check that this is so and if not, check that the 5-way SIL socket strips have been installed and that the display leads have all been correctly trimmed to 4mm, as described earlier.

### Battery holder connections

As shown on Fig.3, the leads from the battery holder are looped through two stress-relief holes in the PCB. They are then soldered to the supply PC stakes, with the red wire going to the positive terminal and the black wire to the negative terminal.

If you are using two 4-AA holders instead of a single 8-AA holder, it will be necessary to connect the two holders in series. That's done by connecting the red wire from one holder to the black wire from the second holder. The easiest way to do that is to feed these red and black wires through the two stress relief holes and connect them to the two terminals marked LOOP on the PCB. The remaining red and black wires are then also fed through the stress relief holes and connected to the 12V PC stakes as before (enlarge the stress relief holes if necessary).

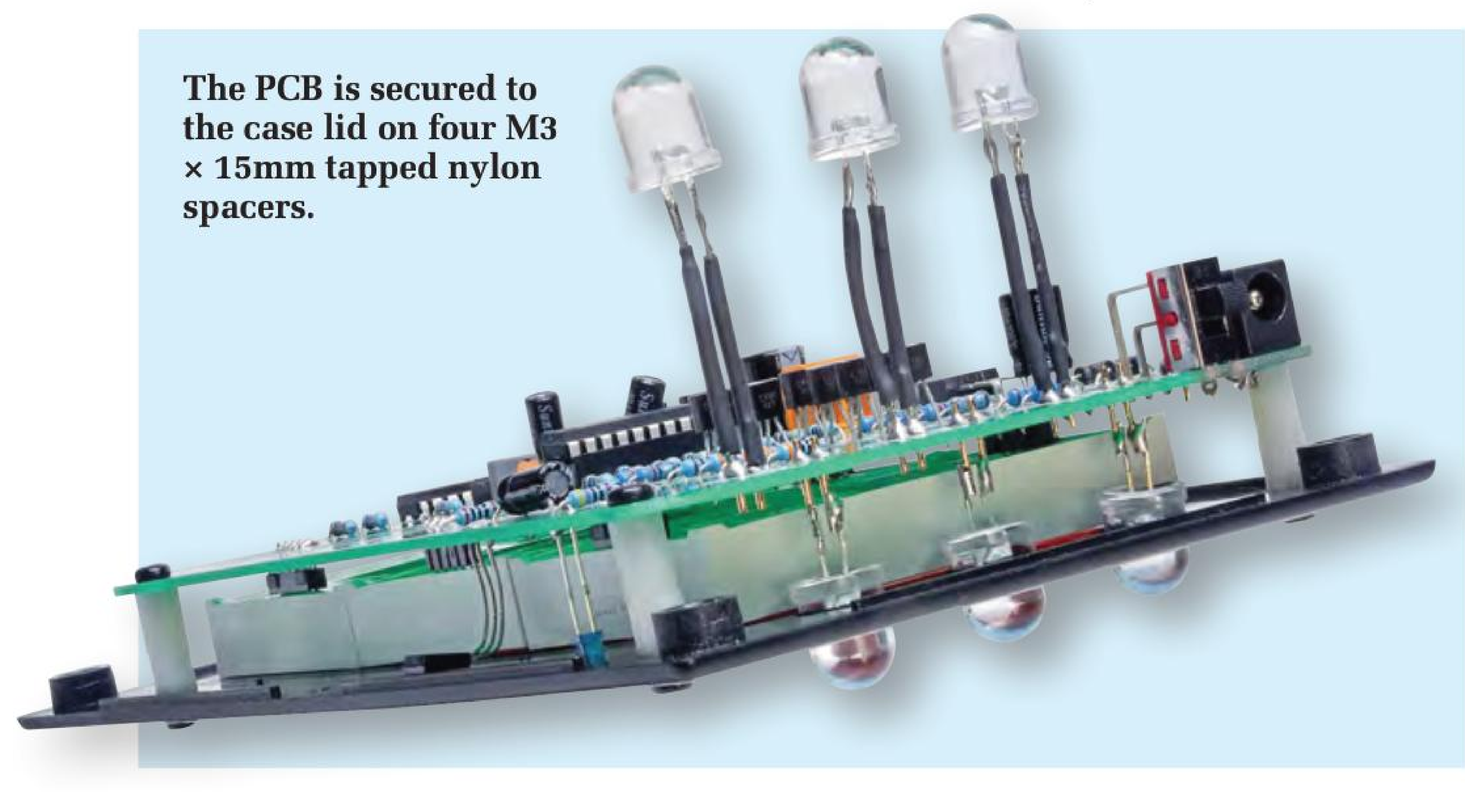
### Case preparation

The PCB assembly can now be put aside while you drill and cut the necessary holes in the case. As mentioned previously, the lid can be replaced with either a Perspex or acrylic transparent red sheet (195 x 110mm). Alternatively, you can use the lid supplied with the box and make a cut-out (fitted with a transparent window) for the 7-segment display.

The first step is to download the drilling template file (in PDF format) from the *EPE* website. Print this template out, then cut out the individual sections and attach them to the case using adhesive tape.

If you are completely replacing the lid, then you don't have to make the rectangular cut-outs for the displays or the infrared receiver IRD1, since they simply sit behind the transparent panel. However, 3mm holes will be required for the four corner-mounting positions where it attaches to the box pillars (see the template). Conversely, if you are using the lid, you will need to make the rectangular cut-outs.

In either case, it's best to use a pilot drill (eg, 1mm) to start the holes and then enlarge them to size. All the small holes are 3mm diameter, while the larger holes are 10mm diameter.



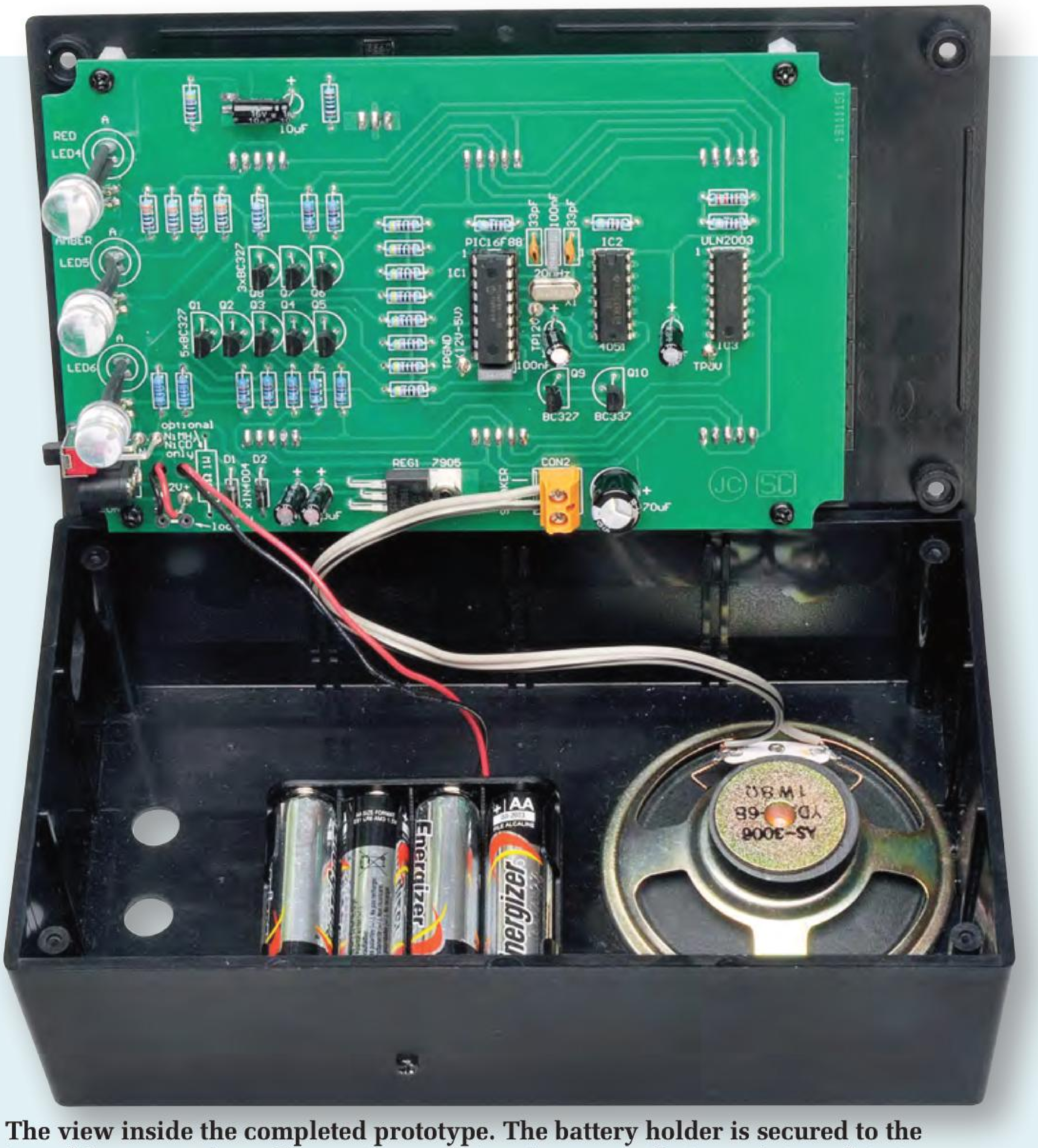
The PCB is secured to the case lid on four M3 × 15mm tapped nylon spacers.

The larger holes should be drilled out to about 4mm and then carefully reamed to the correct size. It's best to ream one of these larger holes first, so that one of the 10mm LEDs just fits. You then push the reamer into the hole as far as it will go and wind a ring of tape around the shaft (on the outside). The remaining five holes can then all be reamed out until the tape stops the reamer from going any further.

Be careful when drilling or reaming Perspex, by the way. It can easily crack if the drill or reamer is forced into the hole.

If using the original lid, the rectangular cut-outs can be made by drilling a series of small holes inside the perimeter, then knocking out the inside piece and filing to shape. Make sure that the large cut-out is exactly the same size as the Perspex window so that the latter is a tight fit. The window can be secured in place using a few spots of contact adhesive.

The rear of the box has to be drilled for LED4-6, while a pattern of 5mm holes is also required for the loudspeaker. In addition, a hole is required in the righthand end of the case to provide access to the DC socket and on/off switch (these holes go in the end of the case adjacent to the 10mm LED holes).



**The view inside the completed prototype. The battery holder is secured to the top of the case using a No.4 × 9mm self-tapping screw that goes into a slot at one end of the holder's plastic moulding.**

### Front-panel label

The front-panel label is available in PDF format on the *EPE* website. It's just a matter of downloading it and printing it out onto an A4-sized synthetic Dataflex or Dataplex sticky label (see panel). This label can then be attached to the lid and the holes cut out using a sharp hobby knife.

Alternatively, you can print out a paper label and attach this to the lid using double-sided tape.

An additional label (Fig.1) shows the function of each of the buttons on the handheld remote and this is affixed to the top panel of the case (see photos).

### Final assembly

Now for the final assembly. The first job is to mount the PCB assembly on the lid (or Perspex panel) using M3 × 15mm spacers and eight M3 × 6mm machine screws. Once that's done, the AA cell holder can be secured inside the case. This is mounted against the base of the box and is secured to the top panel using a No.4 × 9mm self-tapping screw.

Drill a 3mm hole for this screw in the top panel exactly 77mm from the righthand side of the case and 38mm from the front (as measured without the lid). The self-tapping screw is then fed through this hole and goes into one of the slots in the end of the cell holder's plastic moulding.

The last part to go in is the loudspeaker. It's just a matter of securing it in place on the rear panel (ie, the base of the box) using a suitable adhesive such as super glue, contact adhesive or neutral-cure silicone. Smear the glue around the perimeter of the speaker frame, then centre it over the holes made in the base of the box and wait for the adhesive to set. The speaker is then connected to the 2-way screw terminal block on the PCB using figure-8 cable.

### Testing

Now for the smoke test. Check that IC1 is out of its socket, then apply power and check that the voltage between TP +12V and TP GND (ie, between pins 14 and 5 of IC1's socket) is 5V. Note that this reading can be anywhere between 4.75V and 5.25V, depending on the regulator.

If this is correct, switch off and install IC1 into its socket, taking care with its polarity. That done, reapply power and check that the displays show 0:0 but with DISP1 unlit. This unlit digit is due to the leading zero blanking that's incorporated in the

### Dataflex/Datapol labels

(1) For Dataflex labels, go to: **www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_60&products_id=335**

(2) For Datapol labels go to: **www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_55&products_id=326**

## Parts List: Speech Timer

- 1 double-sided PCB, available from the *EPE PCB Service*, coded 19111151, 162.5 × 102mm
- 1 front panel label, 195 × 110mm
- 1 remote control button function label, 23 × 64mm
- 1 UB2 plastic case, 197 × 113 × 63mm
- 1 9-button IR remote control
- 1 CR2025 3V alkaline cell
- 1 141 × 68 × 3mm transparent red acrylic or red Perspex sheet (or 195 × 110mm – see text)
- 1 PCB-mount vertical slider switch (S1)
- 1 8-AA cell holder or 2 × 4-AA holders (optional)
- 8 AA alkaline, NiMH or Nicad cells (optional)
- 1 12V DC 400mA plugpack (optional)
- 1 2.5mm or 2.1mm PCB-mount DC socket (CON1)
- 1 2-way screw terminal block, 5.08mm pitch (CON2)
- 1 76mm 8Ω loudspeaker
- 1 20MHz parallel resonant crystal (X1)
- 1 DIP18 IC socket
- 3 DIP14 IC sockets cut into 6 × 5-way SIL socket strips
- 4 M3 × 15mm tapped nylon spacers
- 9 M3 × 6mm screws
- 1 M3 nut
- 1 No.4 × 9mm self-tapping screw (when 8-AA cell holder is used)
- 1 100mm length of medium-duty figure-8 wire
- 11 PC stakes
- 1 210mm length of 1mm-dia. tinned copper wire
- 1 150mm length of 2mm-dia. heat-shrink tubing

**Semiconductors**

- 1 PIC16F88-I/P microcontroller programmed with 1911115A.hex (IC1)
- 1 4051B single-pole 8-way analogue switch (IC2)
- 1 ULN2003 7-Darlington array (IC3)
- 1 7905 negative 5V regulator (REG1)
- 9 BC327 PNP transistors (Q1-Q9)
- 1 BC337 NPN transistor (Q10)
- 3 58mm 7-segment displays (Jaycar ZD-1850) (DISP1-DISP3)
- 2 waterclear red 2000mcd 10mm LEDs (LED1,LED4)
- 2 waterclear amber 9000mcd 10mm LEDs (LED2,LED5)
- 2 waterclear green 13000mcd 10mm LEDs (LED3,LED6)
- 1 3mm blue LED (LED7)
- 1 TOSOP4136 38kHz IR receiver or similar (IRD1)
- 2 1N5819 1A Schottky diodes (D1,D2)

**Capacitors**

- 1 470µF 25V PC electrolytic
- 5 10µF 16V PC electrolytic
- 2 100nF MKT polyester
- 2 33pF ceramic

**Resistors (0.25W, 1%)**

- 3 4.7kΩ
- 1 2.2kΩ
- 2 1kΩ
- 9 470Ω
- 4 330Ω
- 1 180Ω
- 1 100Ω
- 7 82Ω
- 1 15Ω 1W 5% (optional – see text)

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timer. DISP1 should light up only when it is required to display anything other than zero.

**A hole is cut in the righthand end of the case to provide access to the DC socket and on/off switch.**

Check that the blue acknowledge LED flashes when using the infrared remote. Further operation can then be tested using the remote control, as set out in the following section.

### Remote control

We've already briefly mentioned the SparkFun remote and its button functions. Let's now take a look at the 5-button array below the A, B and C buttons and describe how they control the *Speech Timer*.

The left arrow button is for Reset – it stops and resets the clock timer to zero. In this state, the Up and Down buttons can be used to scroll up or down through the preset timer selections. These selections include the 0:0 setting and the presets 1-2, 2-3, 3-5, 5-7, 10', 15' and so on up to 90' (the – ' – symbol indicates minutes).

Pressing the right arrow button (Start) starts the timer running. It starts with 0:0 displayed and the colon flashing at a one-second rate.

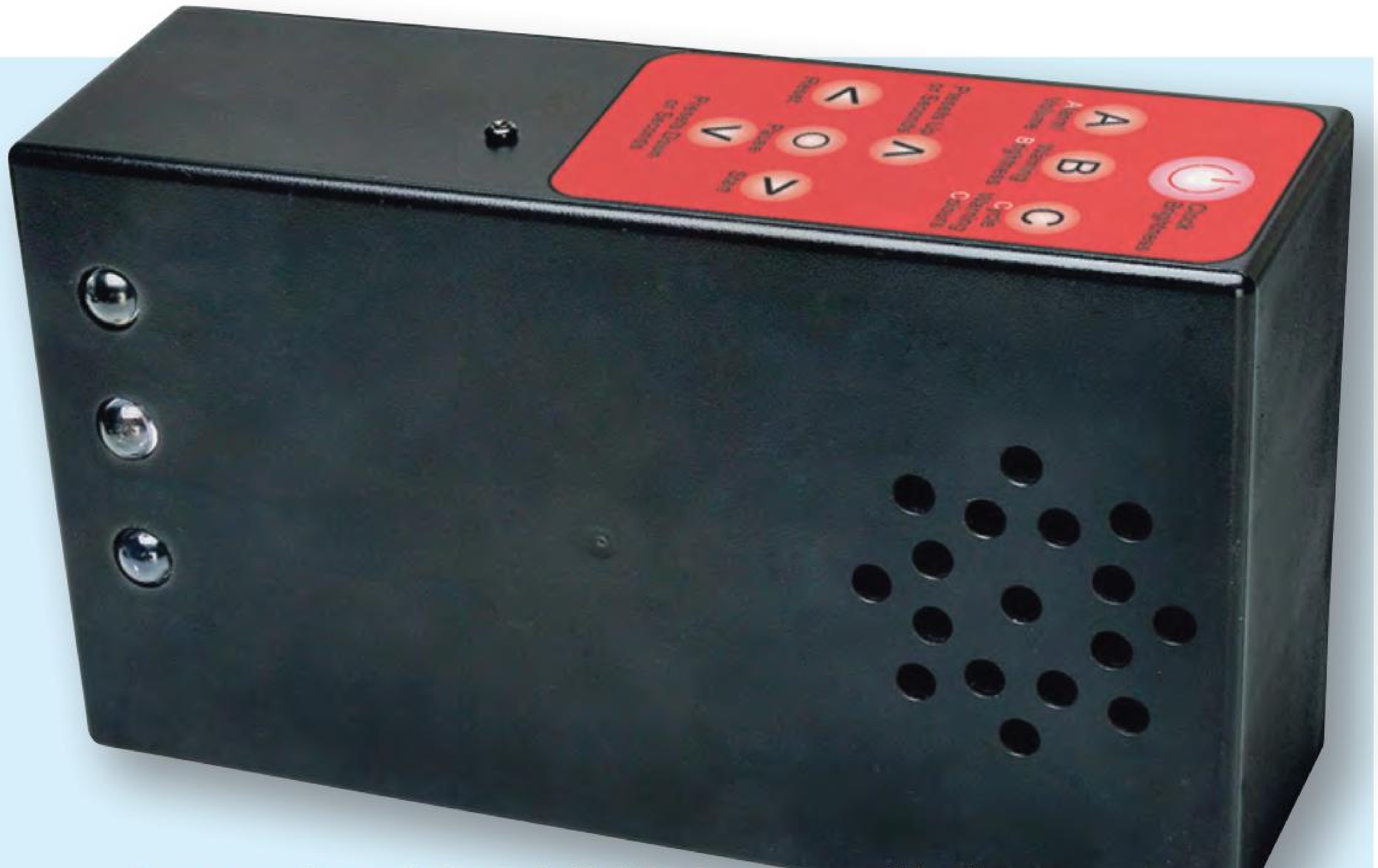
The central 'O' button is the Pause button and is used to stop the clock, so that it ceases incrementing. When paused, the colon stops flashing to indicate that it is in this mode.

Pausing is useful for stopping the *Speech Timer* after the contest so that the overall time can be read off the display (and written down if necessary). The timer can then resume from that time by pressing the Start button or reset back to zero by pressing the Reset (left arrow) button.

Note that there is only a single 'seconds' digit on the timer display and this normally only shows the tens of seconds. It increments by one each 10 seconds when the clock is running.

The exact seconds value can be viewed by pressing the Up or Down button. For example, if the display shows 12:4 (ie, 12 minutes and 40 seconds). Pressing the Up or Down button then causes the display to show the exact number of seconds, eg, 43'' (ie, 43 seconds). This was only partially displayed as the 4 in the 12:4 display.

Note that the – '' – after the 43 is the symbol for seconds and the exact number of seconds is only displayed while the Up or Down button is held pressed.



**A pattern of 5mm holes is drilled in the rear panel for the loudspeaker, while an artwork showing the remote control functions is attached to the top panel.**

Note also that the seconds only show when the timer clock is running or when it is paused but not when reset. The seconds are reset to zero when the unit is reset (left arrow button) and the Up and Down buttons are then instead used to select one of the timer presets.

### Additional buttons

The SparkFun remote's power button is used to adjust the brightness of the 7-segment displays (DISP1-DISP3). These displays can be dimmed up or down, with the dimming direction changed each time the button is pressed. Pressing and holding the button begins dimming in either direction.

The remote's 'B' button is used to independently adjust the Brightness of the indicator LEDs in the same way as the power button.

The 'A' button serves two functions: (1) to manually sound the alarm and (2) to set the volume. If this button is pressed for more than five seconds, it operates as a volume control. After this time, the normally modulated alarm tone becomes continuous, indicating that the unit is in volume setting mode. The 'A' button then has to be released and repressed within 1.25 seconds. When that's done, the modulated alarm tone is restored and the volume begins to change.

If the volume is changing in the wrong direction, it's just a matter of releasing and repressing the 'A' button once more. The volume will then change in the opposite direction. The volume will continue to change for long as you continue pressing the button until it reaches its maximum or minimum level.

Releasing the 'A' button for more than 1.25s exits the volume setting mode and this will be indicated by a brief 'chirp' from the loudspeaker. The alarm (A) button will then operate as normal unless pressed again for longer than five seconds.

The 'C' button cycles through the warning LED indicators, starting with all LEDs off and then lighting the green LED, then the amber LED and finally the red LED in a cyclic fashion for each press of the button.

Finally, note that the timer presets, display brightness and volume settings are stored in EEPROM and are retained when power is switched off. This saves you from having to re-enter the setting each time power is reapplied.

That's it – your *Speech Timer* is ready for action.

## Using the Speech Timer in count-down mode

Normally, all times set for the *Speech Timer*, whether preset or manual, are in count-up mode, eg, a 10-minute speech will start from zero and count up to the set time, at which point the red warning LED will come on. But the counter will continue to run after that and if the speech was being given at a Toastmasters' meeting, there is a risk of disqualification if the speech runs for another minute or more (whatever the rule).

In addition, the *Speech Timer* can also operate in count-down mode. In this case, for a 10-minute speech (say), the *Speech Timer* will start at 10:0 minutes and then count down in 10-second decrements to zero. At zero, the buzzer will also sound briefly.

To access the count-down mode, you simply press the Up button on the remote repeatedly until you get a display of 0:0. Further presses of the Up button then increase the timer setting from 0:0 to 0:1 and so on up to 99:5 (ie, 99 minutes and 50 seconds). Once the timer setting is above 0:0, the remote's Down button can be used to decrease the setting if necessary.

In operation, the Up and Down buttons increase/decrease the timer setting in single step with each button press. Alternatively, holding down a button will cause the timer value to rapidly change up or down.

Once the timer value has been set, pressing the Start (right arrow) button will cause the timer to start counting down to 0:0. When it reaches 0:0, the timer will stop and the buzzer will automatically sound for 2.5s. The previous count-down timer setting can then be restored by pressing the Reset (left arrow) button.

### Warning LEDs

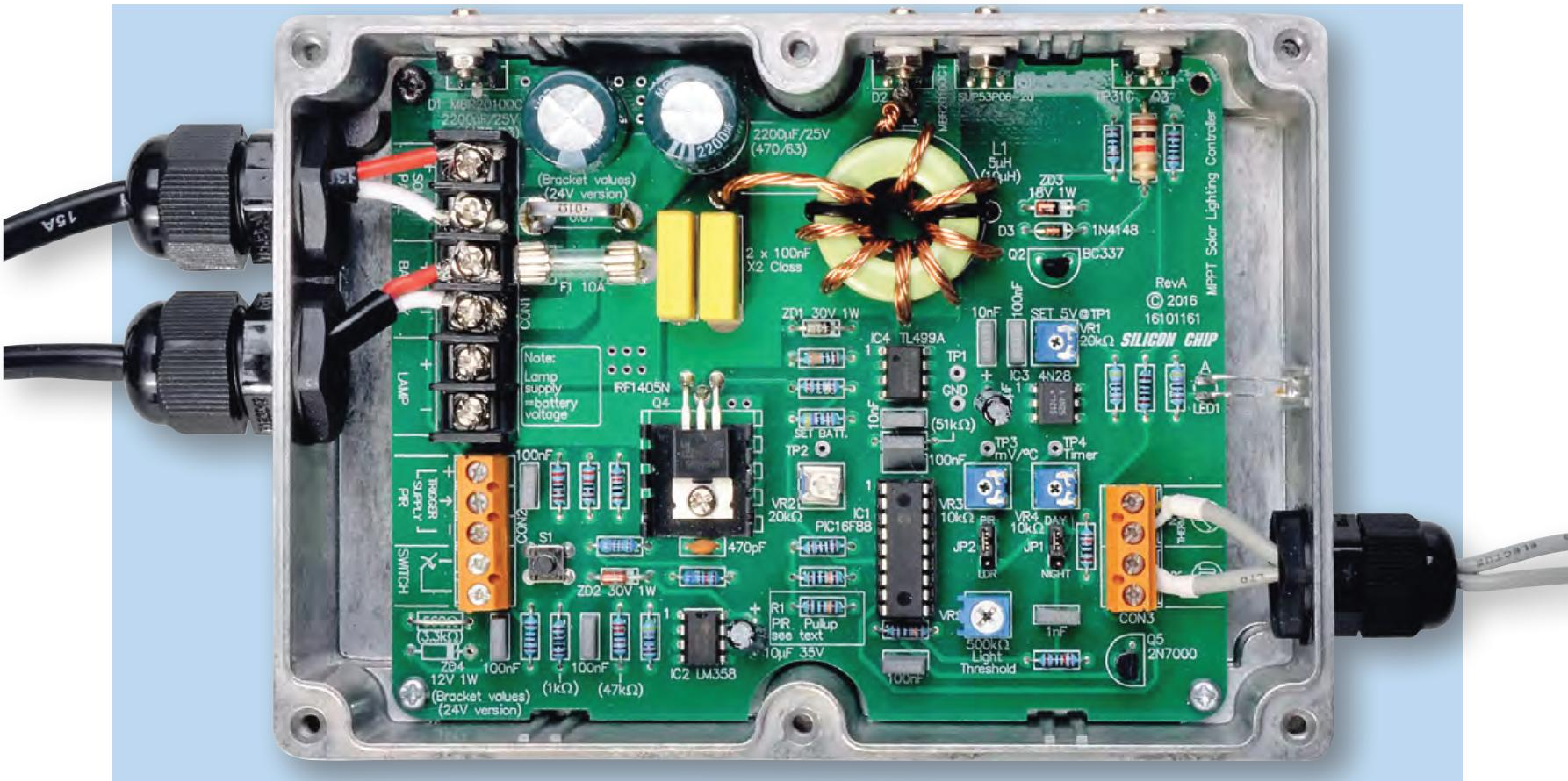
The warning LEDs can also be preset. That's done simply by selecting a warning LED with the remote's 'C' button. The selected LED can then be programmed to turn on at a certain time during the count down using the Up and Down buttons.

You can program each warning LED, but note that you need to select the next LED using the 'C' button before changing the time setting. Note also that, during the count down, you need to have the green LED light before the amber LED, which in turn lights before the red LED. This means that it's best to program the green LED first, followed by the amber LED and then the red LED, each with a progressively lower time setting.

The warning LED programming an be cancelled by setting the timer to 0:0 and then cycling through each LED with the 'C' button.

### Restoring count up timing

Pressing the Down button when the timer is at 0:0 re-selects the preset periods, starting with 90', then 80'... This resets the *Speech Timer* to function as a count-up timer and the presets can then be selected using the Up and Down buttons.


MPPT Solar Lighting Controller
RevA
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16101161
SILICON CHIP
F1 10A
2 x 100nF X2 Class
L1 5μH (10μH)
IC4 TL499A
IC3 4N28
IC1 PIC16F88
IC2 LM358
Q4 IRF1405N
Q5 2N7000
Q2 BC337
D3 1N4148
ZD1 30V 1W
ZD2 30V 1W
ZD3 18V 1W
ZD4 12V 1W
VR1 20kΩ
VR2 20kΩ
VR3 10kΩ
VR4 10kΩ
VR5 500kΩ Light Threshold
LED1
S1
CON1
CON2
CON3
Note: Lamp supply = battery voltage
(Bracket values) (24V version)
2200μF/25V (470/63)
15A

# Solar MPPT Charger & Lighting Controller

## Part 2: By JOHN CLARKE

**This *Solar MPPT Charger/Lighting Controller* uses solar panels to charge a 12V or 24V battery and then works with LDR/PIR sensors to run 12V DC lighting or an inverter. Last month, we gave the circuit details; this month, we show you how to build it and describe the setting-up procedure.**

THIS UNIT is easy to build, with all parts mounted on a PCB available from the *EPE PCB Service*, coded 16101161 and measuring 141 × 112mm. This is housed in a diecast case measuring 171 × 121 × 55mm. The PCB is secured to integral mounting points inside the case and is shaped so that it fits neatly around the central pillars on either side.

As well as providing a rugged assembly, the diecast case also provides heatsinking for diodes D1 and D2, power MOSFET Q1 and power transistor Q3.

Fig.7 shows the parts layout on the PCB. Begin the assembly by installing the resistors – use a DMM to check each value as it is installed. Note that the 'in brackets' values shown for some of the resistors are for the 24V version of the *Solar Charge & Lighting Controller*.

Note also that the 0.01Ω 3W resistor (just above fuse F1) should be left out at this stage of the assembly. It goes in after the fuse clips have been installed (see below).

Diode D3 can go in next, followed by zener diodes ZD1, ZD2 and ZD3. These must all be mounted with the correct orientation, as shown on Fig.7. Leave power diodes D1 and D2 out for the time being.

Zener diode ZD4 is not normally installed and a wire link is used for resistor R2. This is the standard set-up if using a PIR sensor that can handle a supply of up to 14.4V.

**Conversely, ZD4 must be installed if you are using a PIR sensor that's rated at 12V maximum. If ZD4 is fitted, you must also use a resistor for R2 instead of a link.** Use a 270Ω resistor for a 12V battery and a 1.2kΩ resistor for the 24V version.

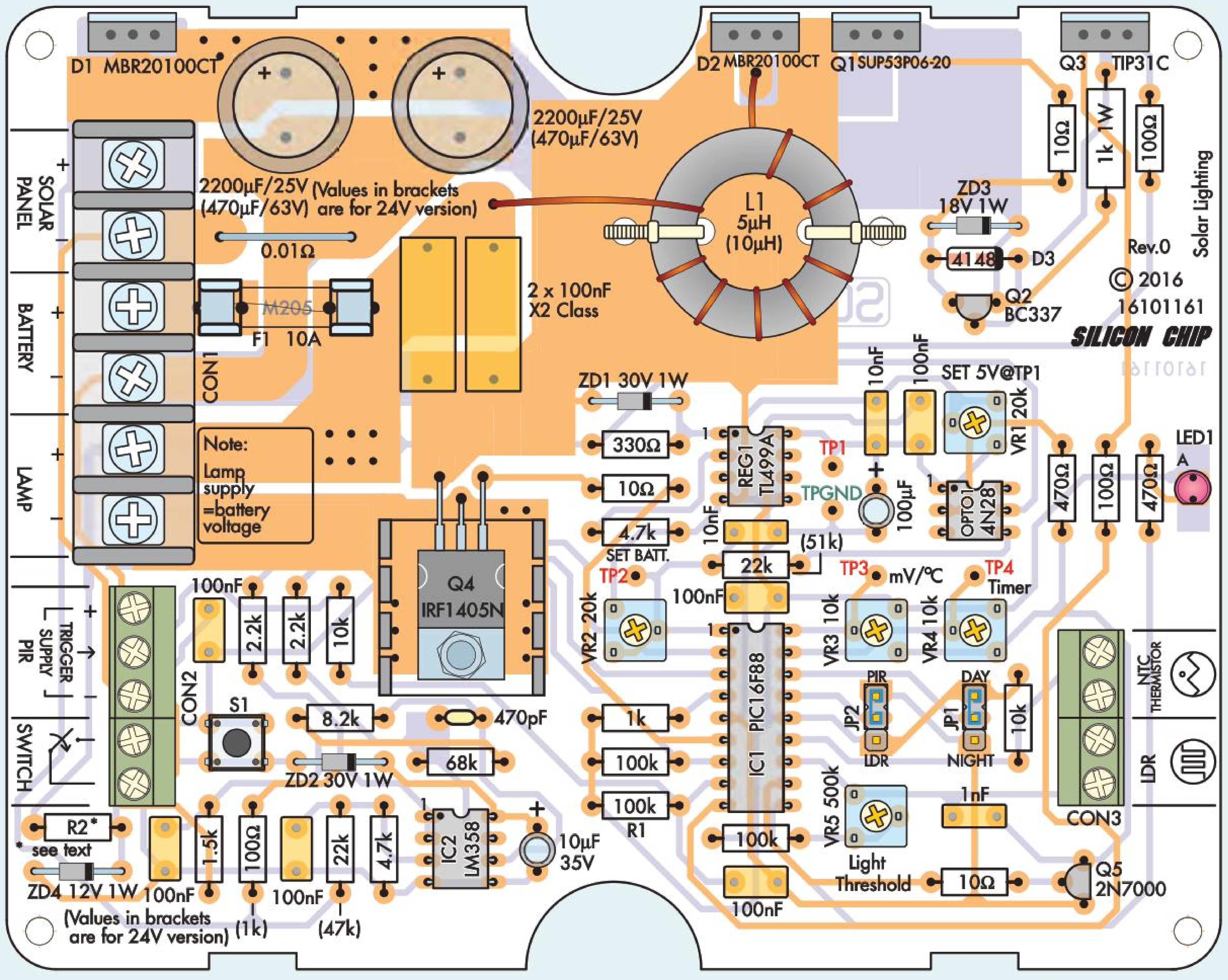

D1 MBR20100CT
2200µF/25V (470µF/63V)
2200µF/25V (Values in brackets (470µF/63V) are for 24V version)
D2 MBR20100CT
Q1 SUP53P06-20
Q3 TIP31C
SOLAR PANEL
BATTERY
LAMP
CON1
0.01Ω
M205
F1 10A
2 x 100nF X2 Class
L1 5µH (10µH)
ZD3 18V 1W
4148 D3
Q2 BC337
10Ω
1k 1W
100Ω
Solar Lighting
Rev.0
© 2016
16101161
SILICON CHIP
ZD1 30V 1W
330Ω
10Ω
4.7k
SET BATT.
REG1 TL499A
TP1
TPGND
10nF
100nF
SET 5V@TP1
VR1 20k
100µF
OPTO1 4N28
470Ω
100Ω
470Ω
LED1
A
Note: Lamp supply =battery voltage
Q4 IRF1405N
22k
(51k)
TP2
TP3
mV/°C
TP4
Timer
VR2 20k
VR3 10k
VR4 10k
IC1 PIC16F88
TRIGGER SUPPLY PIR
SWITCH
CON2
2.2k
2.2k
10k
S1
8.2k
470pF
1k
100k
100k
R1
68k
ZD2 30V 1W
PIR
LDR
JP2
DAY
NIGHT
JP1
10k
1nF
NTC THERMISTOR
LDR
CON3
R2* see text
ZD4 12V 1W
1.5k
100Ω
22k
4.7k
IC2 LM358
10µF 35V
VR5 500k
Light Threshold
10Ω
Q5 2N7000
(Values in brackets are for 24V version)
(1k)
(47k)

**Fig.7: follow this parts layout diagram to assemble the PCB. Power devices D1, D2, Q1 and Q3 must all be mounted on 10mm lead lengths, while LED1 is mounted on 20mm lead lengths so that it can later be bent over to protrude through the side of the case. Refer to the text for the winding details for inductor L1.**

In particular, note that ZD4 and a 1.2kΩ resistor (for R2) must be used for the 24V version, unless the PIR can operate directly from a 28.8V supply.

IC1's socket can now go in, followed by IC2, REG1 and OPTO1 which can all be directly soldered to the PCB. Check that these parts are all correctly oriented before soldering their pins. Trimpots VR1-VR5 can then be installed. VR1 and VR2 are 20kΩ types and may be marked as 203. VR3 and VR4 are 10kΩ trimpots (103), while VR5 is a 500kΩ trimpot (504).

Once the trimpots are in, fit PC stakes to test points TP1-TP4 and TP-GND, then fit PC stakes to terminate the leads from inductor L1. That done, install switch S1 and the 3-way pin headers for JP1 and JP2.

Transistors Q2 and Q5 are next on the list. Make sure that Q2 is a BC337 and that Q5 is a 2N7000. MOSFET Q4 can then be installed; it's mounted horizontally on a small finned heatsink with its leads bent down through 90° so that they go through their respective holes in the PCB. Be sure to secure the assembly in place using an M3 × 6mm machine screw, washer and nut before soldering the leads.

There is no need to electrically isolate Q4's tab from the heatsink, so an insulation washer is not required.

Now for the fuse clips. These must go in with their retaining tabs on the outside, otherwise you will not be able to fit the fuse correctly. Once these are in, install the 0.01Ω 3W resistor.

The next step is to fit all the capacitors. Be sure to orient the electrolytic types correctly. Note that the values and voltage ratings of the two large electrolytic capacitors at top left depend on whether the unit is built for 12V or 24V operation.

Follow with screw terminal blocks CON1-CON3. Note that CON1 uses large screw terminals in order to handle the heavy current requirements for the solar panel, battery and lamp connections. CON2 and CON3 are smaller units and are made up by dovetailing separate connectors together. In particular, CON2 uses a 3-way and 2-way connector, while CON3 uses two 2-way connectors.

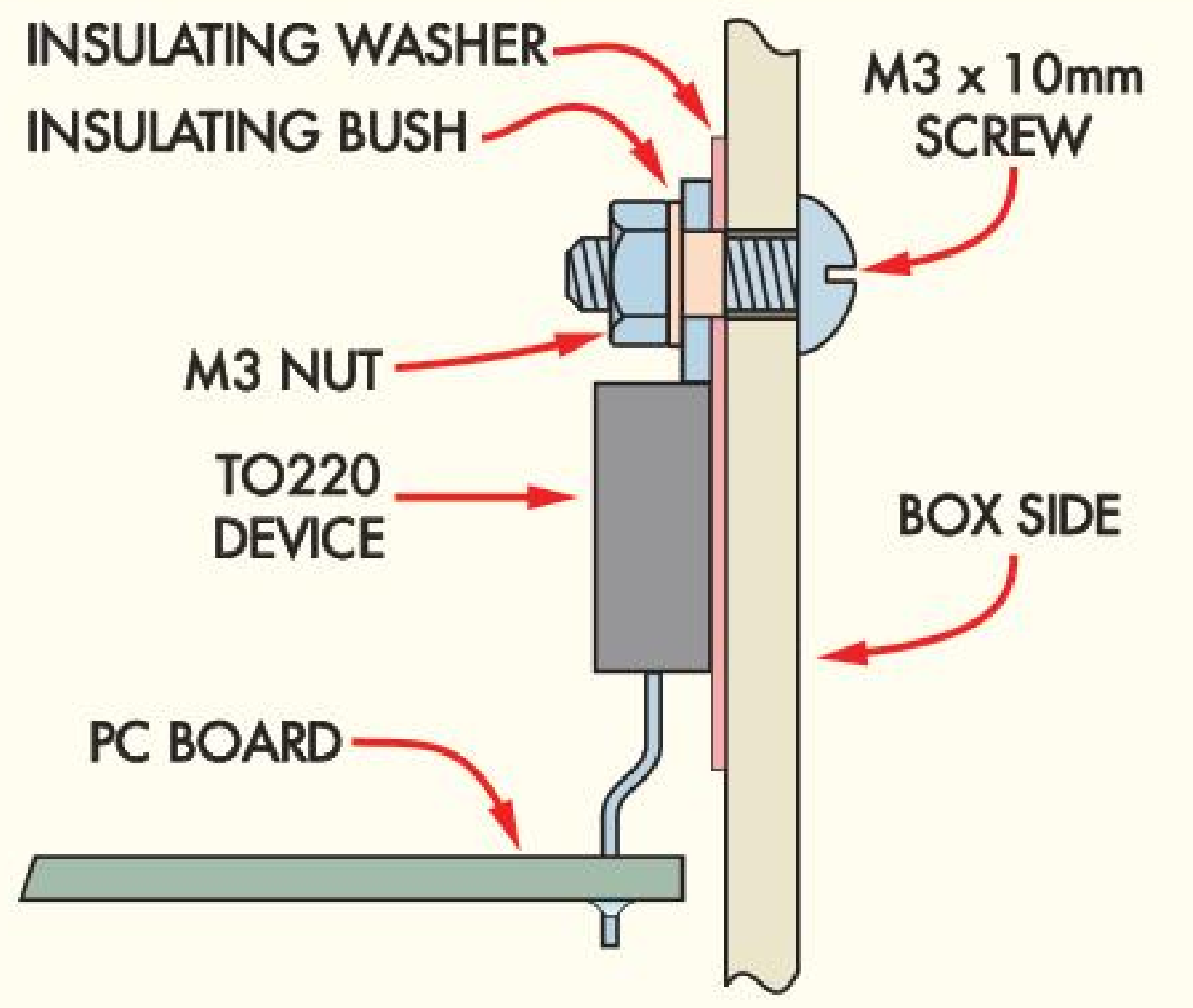
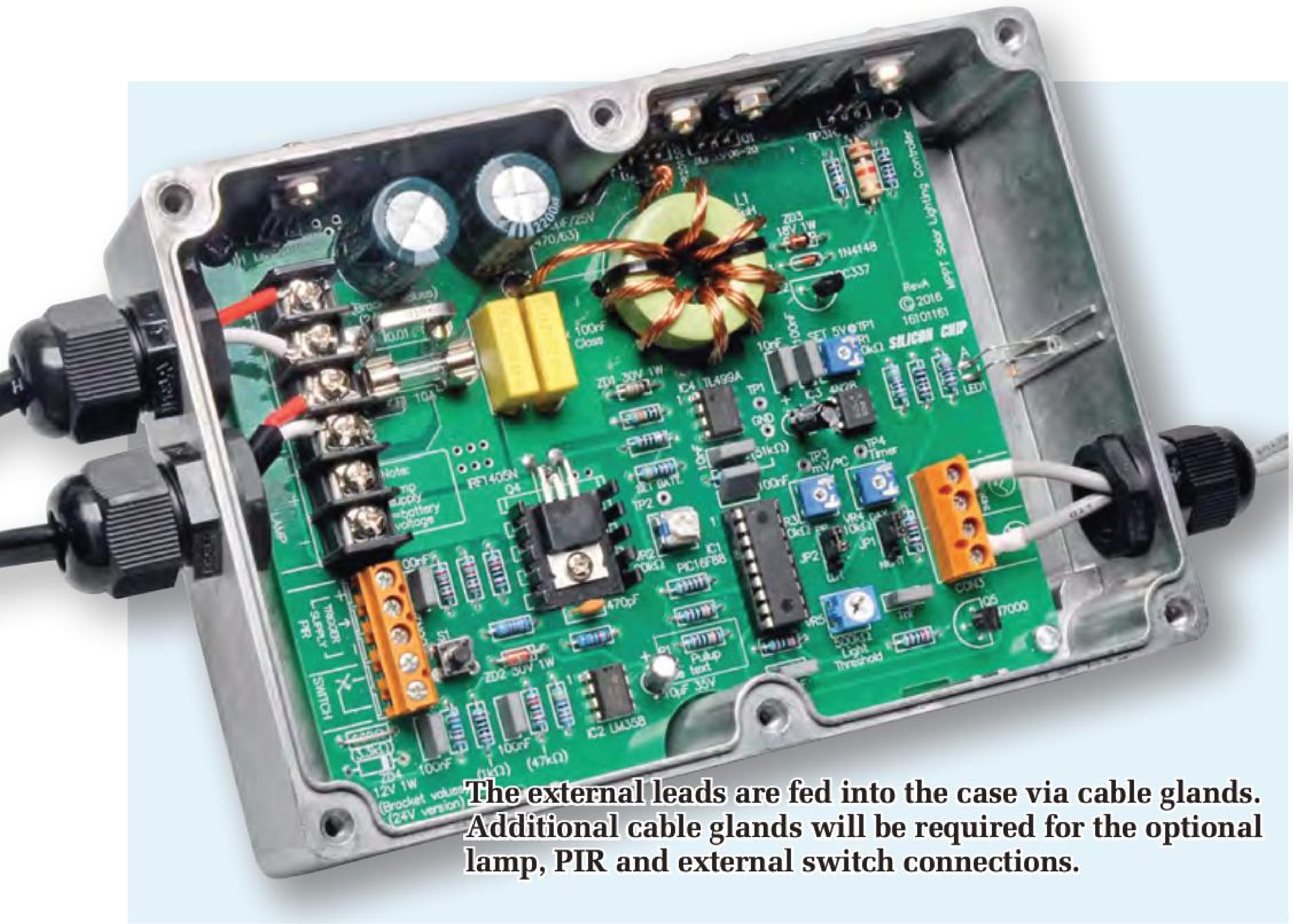

INSULATING WASHER
INSULATING BUSH
M3 x 10mm SCREW
M3 NUT
TO220 DEVICE
BOX SIDE
PC BOARD

**Fig.8: power devices D1, D2, Q1 and Q3 must be electrically isolated from the case using insulating washers and insulating bushes. After mounting each device, use a DMM (set to a high-ohms range) to check the metal tab is isolated from the case.**

Make sure that CON2 and CON3 are oriented with their openings towards the outside edge of the PCB.

## Power devices

Power devices D1, D2, Q1 and Q3 are all installed with their mounting tab holes about 22mm above the PCB. In practice, this means mounting the devices on 10mm lead-lengths and that's best done with the aid of a 10mm-wide cardboard



The external leads are fed into the case via cable glands. Additional cable glands will be required for the optional lamp, PIR and external switch connections.

spacer slid between the device leads. Be careful not to get these devices mixed up and note that the metal tabs go towards the outside edge of the board.

LED1 (centre, right) must be mounted so that it can later protrude through a hole in the side of the diecast case. It's just a matter of soldering it in at full lead length, then bending its leads over at right angles about 8mm above the PCB (eg, by bending it over an 8mm cardboard spacer). Be sure to orient the LED correctly; its anode (A) lead is the longer of the two.

### Winding inductor L1

Inductor L1 is wound using six strands of 0.5mm enamelled copper wire that are all twisted together. Begin by cutting 6 × 416mm lengths of wire, then strip about 15mm of enamel off each wire at one end. Lightly tin these wire ends, then twist the ends together and solder them.

Next, secure this soldered end in the chuck of a hand or battery-powered drill and twist all the wires together, so that each wire twists by 360° approximately every 20mm (see photos).

That done, wind seven turns (or 10 turns for the 24V version) through the toroid, spacing the turns evenly. Once they're on, position the inductor on the PCB and bend the soldered end so that it mates with one of the inductor's PC stakes. The other end can then be positioned to mate with its PC stake and cut to length.

Finally, strip back the enamel from the leads at this end, twist and solder them together and install the inductor on the PCB. A couple of cable ties fed through adjacent holes on either side of the inductor are then used to secure it in place.

Note that multiple strands of wire are used to minimise the impact of skin effect. If a single, larger wire had been used instead, its effective resistance at the switching frequency would be higher, leading to greater losses and more heating. The approach taken here to reduce skin effect is similar to that of using Litz wire, except that the twisted wires are larger.

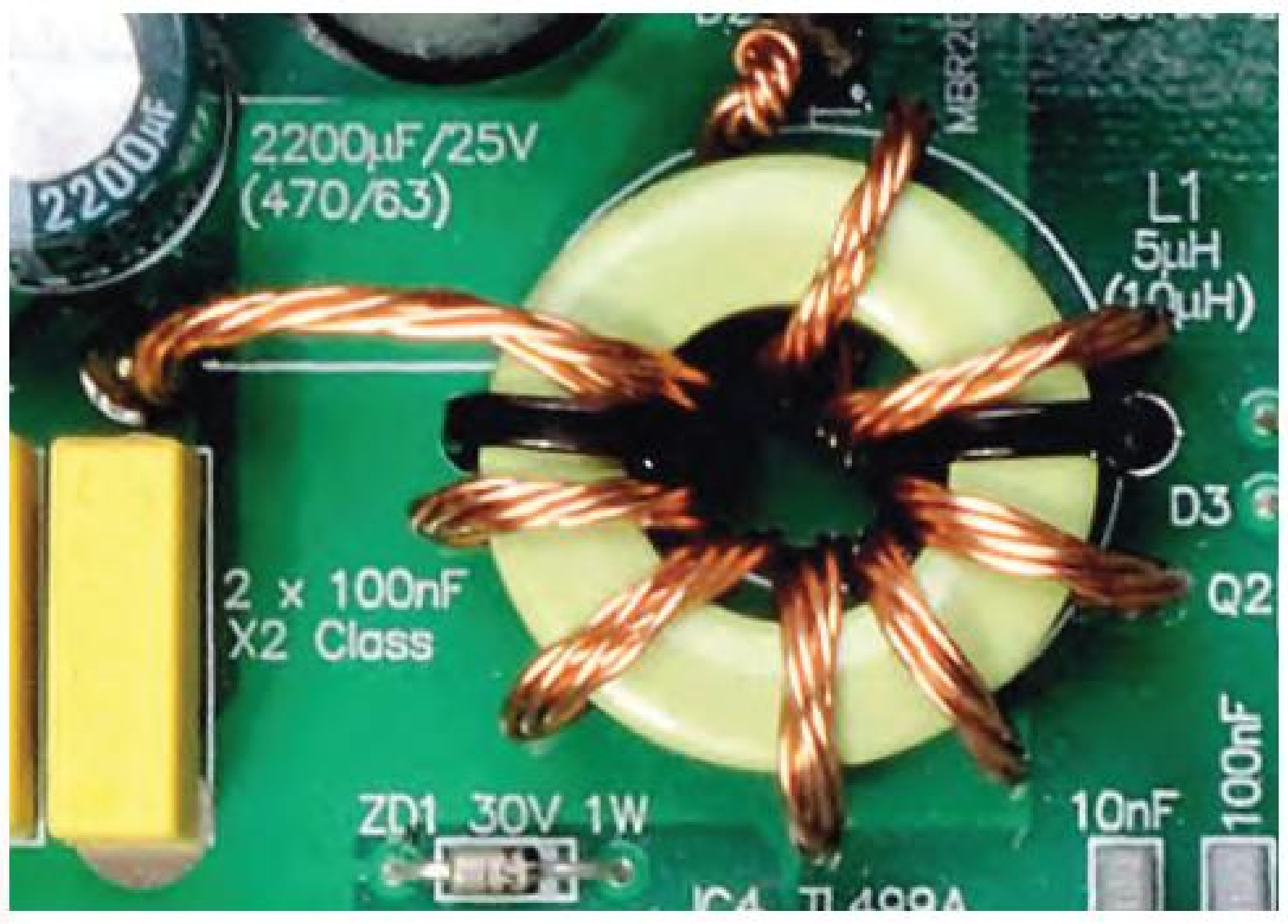
That completes the PCB assembly. The next step is to prepare the case.

### Case drilling

The first step here is to drill two holes in one side of the case to accept two IP68 8mm cable glands, plus another hole in the opposite side for a 6.5mm cable gland. To do that, position the PCB inside the case and carefully mark out the positions for these cable glands. As shown in the photos, they are positioned opposite CON1 and CON3, and are centred vertically.

The PCB can then be removed from the case and the holes drilled and reamed to size. Deburr all edges with a small round file.

That done, the PCB can be temporarily repositioned in the case and the mounting holes for the four power devices (D1, D2, Q1 and Q3) and for LED1 marked out. Drill these holes to 3mm, then use an oversize drill to remove any metal swarf so that the area around each hole is perfectly smooth. This latter step is necessary to prevent punch-though of the insulating washers used with the power devices.



**Inductor L1 is made by twisting six 416mm-long strands of 0.5mm copper wire together and then winding on seven (or 10) turns – see text.**

The PCB can now be secured inside the case using the supplied screws and the four TO-220 power devices attached to one side of the case, as shown in Fig.8. Note that it is necessary to isolate each device tab from the case using an insulating washer and insulating bush.

Once they have been installed, use a digital multimeter (set to read ohms) to confirm that the metal tabs are indeed isolated from the metal case. If a low resistance reading is found, check that the silicone washer for that particular TO-220 device has not been punctured by metal swarf.

If it has, then clear away the swarf and replace the insulating washer.

### Setting up

The step-by-step setting-up procedure is as follows:

1) Check that IC1 is out of its socket, then fit the fuse and apply 12V to the battery input terminals.
2) Connect a DMM between TP1 and TPGND and adjust VR1 for a reading of 5.0V.
3) Disconnect the 12V supply and wait for the 5V rail (measured at TP1) to drop to near 0V.
4) Plug IC1 into its socket, then reconnect the 12V supply.
5) Measure voltage across the battery terminals, multiply this by 0.3125.
6) Press switch S1 and wait for a few seconds, then connect a DMM between TP2 and TPGND and adjust VR2 so that the DMM reads the calculated figure. For example, if the battery terminal voltage is 12.0V, TP2 should read 3.75V.
7) Determine the recommended temperature compensation (in mV/°C) for your battery by looking up its

## Using the Solar Charger/Lighting Controller with 24V batteries

**As stated last month, the *Solar MPPT Charger/Lighting Controller* can also be used with 24V batteries and 24V solar panels. However, this requires some component changes to the circuit and these are indicated in brackets on Fig.7. In summary, the required changes are as follows:**

1) The 22kΩ resistor at pin 3 of IC2a is changed to 47kΩ, the 100Ω resistor feeding ZD2 is changed to 1kΩ and the 22kΩ resistor at the AN2 input of IC1 is changed to 51kΩ.
2) The 2200µF 25V low-ESR capacitors are changed to 470µF 63V low-ESR types.
3) The number of turns on inductor L1 is increased from seven to 10.
4) If used, R2 should be increased to 1.2kΩ.

**Several set-up changes are also required:**

1) The voltage at TP2 (set by VR2) must now be the battery voltage x 0.15625 (instead of 0.3125).
2) The voltage set at TP3 for temperature compensation (step 8 in the setting up procedure) must be half that set for 12V operation. For example, for 38mV/°C compensation with a 24V battery, TP2 should read 1.9V (not 3.8V).

specifications. Usually, there will be a graph which shows the battery's fully charged voltage against temperature – determine the mV/°C figure from this graph.

**8)** Connect the DMM to TP3, hold down switch S1 and adjust VR3 until the meter shows the required temperature compensation value. This reading will be in the range of 0-5V, representing 0-50mV/°C; ie, 1V = 10mV/°C.

Note that this applies to lead-acid batteries only. If you have a $LiFePO_4$ battery, set VR3 fully anticlockwise for a 0V reading at TP3.

### Thermistor connection

Thermistor TH1 can be directly connected to CON3 inside the case if you are not too concerned about temperature compensation. However, you would then be relying on the temperature within the case being similar to that of the battery.

The odds are that the case and battery temperatures will be different, though. So, instead of mounting it in the case, the best way to mount the thermistor is to tape it to the side of the battery and connect it to CON3 using single-core shielded cable (fed in via the cable gland). This lead should be soldered to the thermistor and the solder joints insulated with heatshrink tubing (polarity is unimportant).

**Note that you must have the thermistor connected if the mV/°C adjustment, as measured at TP3 is above 0V.** If it's left out, LED1 will flash to give the disconnected thermistor indication and charging will not take place. Conversely, if VR3 is set to give 0V at

## Cable resistance must be kept low

When the *Solar Charge Controller* is used with a 120W panel, the charging current to the battery can be as high as 10A. Hence, the cable resistance between the *Charge Controller* and the battery should be made as low as possible, otherwise voltage losses will affect the changeover from the bulk charge to the absorption stage of charging. This will reduce the overall charging efficacy.

**To minimise these voltage losses, mount the charger close to the battery and use heavy duty cables.** For a total cable length of less than one metre (ie, total wire length for the positive and negative wires), cables with a cross-sectional area of 1.29$mm^2$ (eg, 41 × 0.2mm) can be used. This will result in a voltage loss of just 100mV at 10A.

For longer wire lengths, use heavier duty cable. For example, 8-gauge wire with 7 × 95/0.12mm wire and a cross sectional area of 7.5$mm^2$ can be used with a total length of up to 5.5m.

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- Smallest and lightest
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## Lighting and inverter options

As stated last month, jumpers JP1 and JP2 select the various lighting options. Here are a few suggestions:

**(1) Night-time garden lighting:** the light sensor allows the lights to switch on at dusk and they can remain lit for a preset period of up to eight hours, as set by the timer. Alternatively, you may wish to have the lights lit for the entire night and to switch off automatically at sunrise, provided there is sufficient battery capacity.

**(2) Security or pathway lighting:** the lights can be set to switch on after dusk but only when someone approaches the area. In this case, a PIR movement detector switches on the lights while the timer switches off the lights after the time-out period, typically 1-3 minutes or longer (8-hour maximum).

**(3) Shed lighting:** in this case, you may opt to switch the lights on and off using an external pushbutton switch. The lights can remain on until they are switched off again or they can switch automatically after a preset period, or at sunrise (as detected by an LDR).

Normally, the controller would be set so that the lights only come on when it is dark. However, you might want the lights on during day in a shed and this can be done using the third option listed in Table 1 last month; ie, JP1 in the night position, JP2 in the LDR position and the LDR left disconnected.

### Using an inverter

As mentioned last month, you can directly switch up to 10A of 12V DC lighting via the LAMP terminals on CON1. Alternatively, instead of using 12V lamps, you can use an inverter to run 230VAC lamps.

This latter option requires the addition of an external relay (rated at 12VDC 150A) to switch the inverter on and off.

Fig.10 shows the details, and as can be seen, the external relay's coil is connected across the LAMP terminals of CON1, while its NO (normally open) contacts switch the positive supply line from the battery through to the inverter. The negative supply terminal in the inverter is directly connected to the negative battery terminal.

A 150A relay is recommended to cope with the surge currents drawn by the inverter. If you use a 24V battery, you will need to connect a 47Ω 10W resistor in series with the relay's 12V coil. Assuming that the relay has a 50Ω coil, this 47Ω resistor will effectively halve the voltage that's applied to the coil.

Note that the supply wiring to the relay and to the inverter must be rated to carry the inverter's current. A 12V 600W inverter, for example, will need supply wiring that's capable of carrying at least 50A.

### Battery size

A minimum battery capacity of 80Ah is recommended. A larger battery can be used, provided you don't draw more from the battery than the solar panels can top up. If you use more power than the solar panels can provide, then the battery will eventually discharge.

### $LiFePO_4$ charging

When using a $LiFePO_4$ battery, the mV/°C setting using VR3 must be set to 0mV/°C. This enables the correct

TP3 (ie, 0mV/°C compensation), such as when using a $LiFePO_4$ battery, the thermistor can be left disconnected.

**Connecting the LDR**

The LDR will need to be connected to CON3 if you want the lighting to be controlled by the ambient light level. You then have to set jumpers JP1 and JP2 to determine whether the lights come on at night or during the day – see Table 1 last month.

As with the NTC thermistor, the LDR can be attached via a length of single-core shielded cable (or use figure-8 lead). The LDR should be mounted in a location where it receives ambient light only; not light from the lamps being switched by the *Solar Charge/ Lighting Controller*.

An external switch can also be used for lamp on/off control. This should be a momentary-contact pushbutton switch. This is connected to CON2's

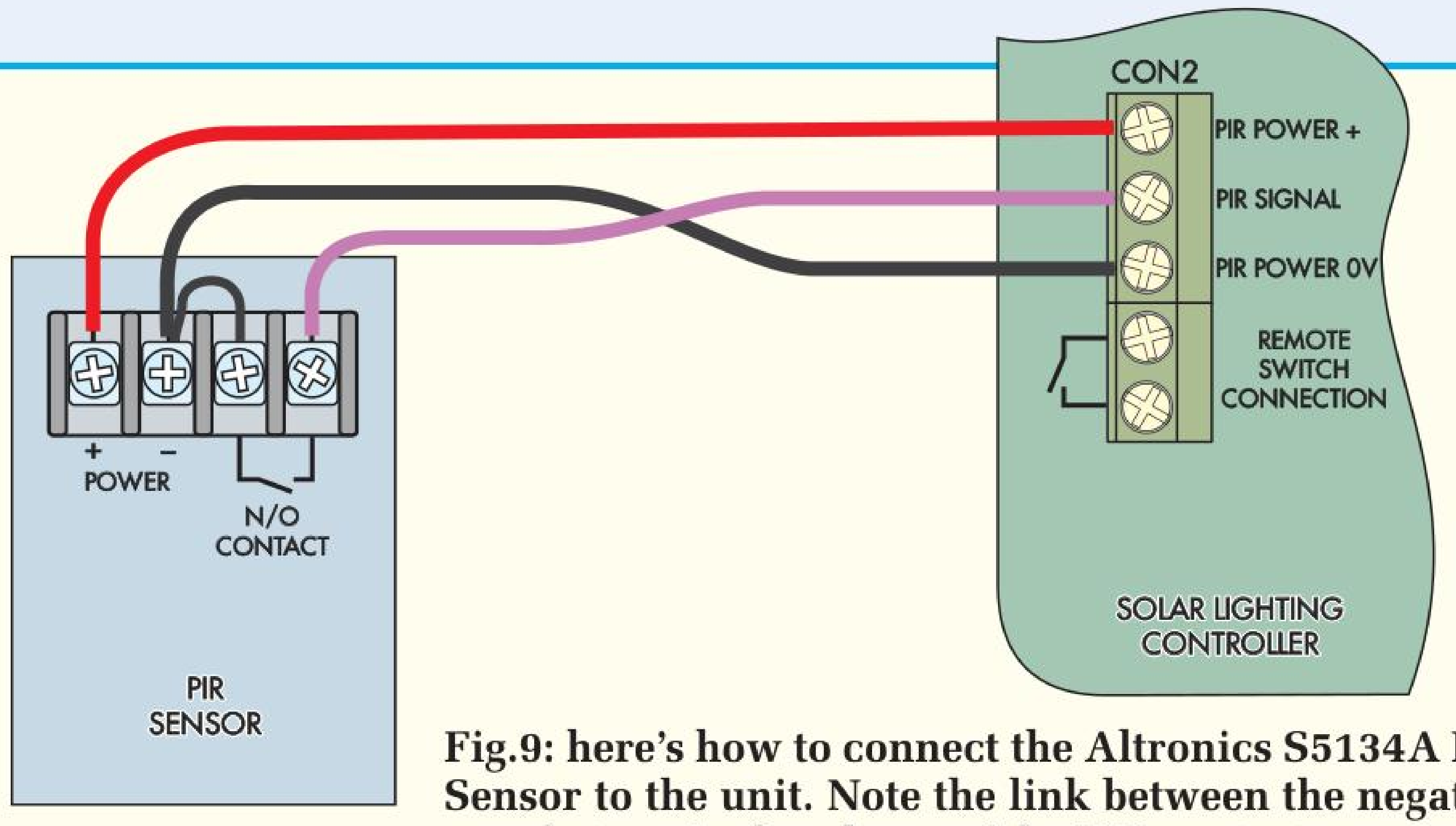

**Fig.9: here's how to connect the Altronics S5134A PIR Sensor to the unit. Note the link between the negative supply terminal and one of the NO contacts.**

## Mounting and connecting a PIR sensor

An Altronics S5314A PIR sensor was used with our prototype unit, but other similar PIR sensors will also be suitable.

The Altronics sensor can be configured for either a normally open (NO) or normally closed (NC) output. In this case, it's necessary to select the NO option using the supplied jumper.

Once that's done, the PIR sensor is connected to CON2 on the *Solar Charge/ Lighting Controller,* as shown above in Fig.9. Note the link between the PIR's negative power terminal and one of its NO contacts. The PIR's other NO contact connects to the PIR signal input on CON2.

In operation, the signal input terminal is normally pulled to +5V via R1 (100kΩ) on the controller's PCB. However, when movement is detected, the PIR's contacts close and the signal input is pulled down to 0V, thus triggering the controller and turning on the lights.

When mounting the PIR sensor, be sure to position it so that it covers the desired detection area. You can test its coverage by temporarily mounting it in position, connecting the 12V supply from CON2 and watching the detect LED in the PIR sensor light as you move around the detection area.

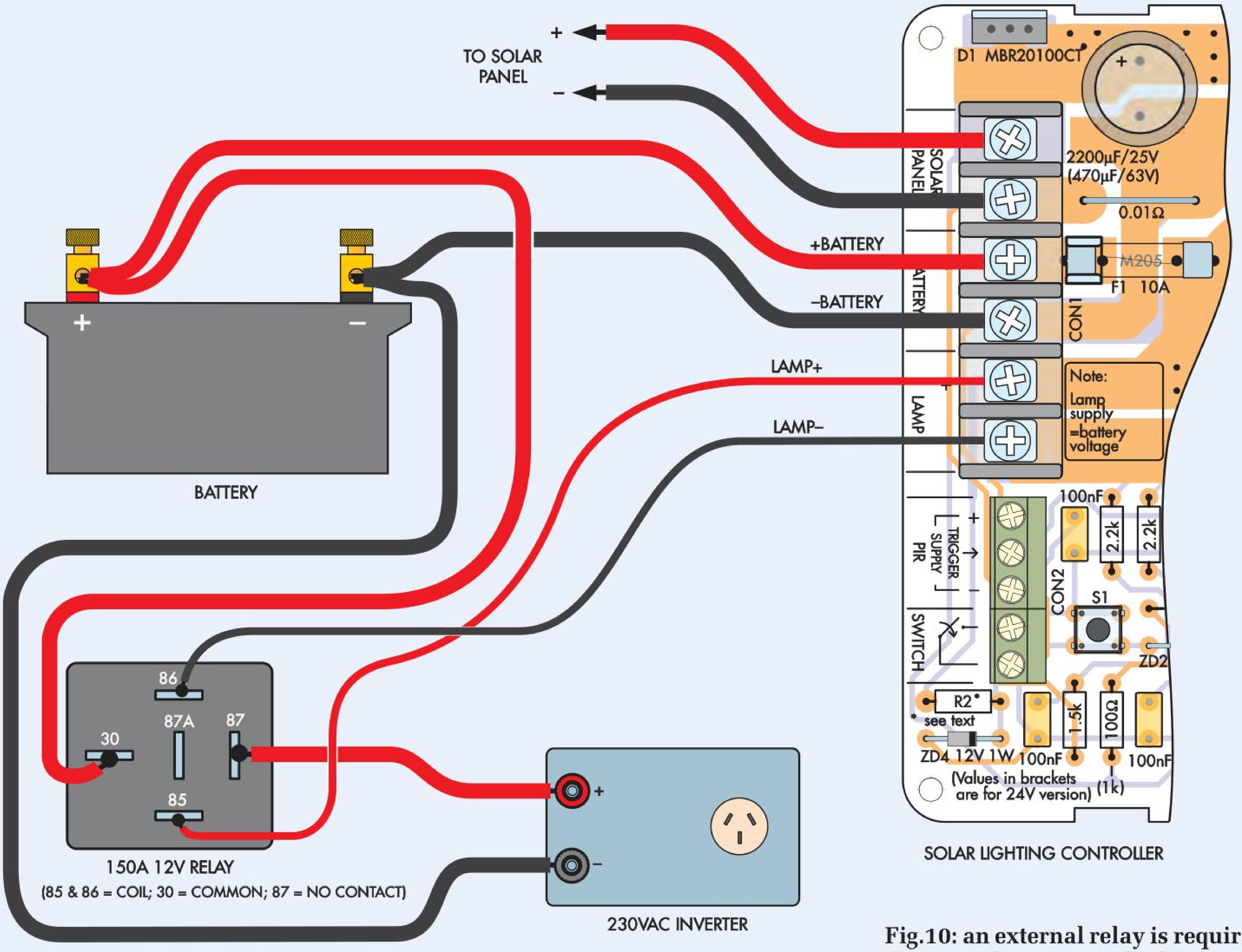
TO SOLAR PANEL
+
–
BATTERY
+
–
+BATTERY
–BATTERY
LAMP+
LAMP–
SOLAR PANEL
BATTERY
LAMP
CON1
D1 MBR20100CT
2200µF/25V (470µF/63V)
0.01Ω
M205
F1 10A
Note: Lamp supply =battery voltage
100nF
2.2k
2.2k
TRIGGER
SUPPLY
PIR
SWITCH
CON2
S1
ZD2
R2*
* see text
ZD4 12V 1W
100nF
1.5k
100Ω
100nF
(Values in brackets are for 24V version)
(1k)
SOLAR LIGHTING CONTROLLER
86
87A
87
30
85
150A 12V RELAY
(85 & 86 = COIL; 30 = COMMON; 87 = NO CONTACT)
230VAC INVERTER

**Fig.10: an external relay is required if you wish to power the lamps via a 230VAC inverter. Note that the wiring to the battery and to the inverter must be rated to carry the inverter's maximum current.**

charging cycle for this battery chemistry.

In addition, a cell balancer should be connected to the balance connector on the battery. This is necessary to ensure that each cell that makes up the battery is charged to the same level as the others. A suitable cell balancer will be published next month.

switch terminals using figure-8 cable (ie, it connects in parallel with switch S1 on the PCB).

Another option is to connect a PIR sensor to CON2 and use that to control the lamp switching. An accompanying panel in this artricle describes how to do this.

### Setting the time-out period

Depending on your application, the timer will need to be set to an appropriate period. The time-out period can be adjusted from two seconds (2s) up to about eight hours using VR4.

Table 3 shows the time-out with respect to the voltage on TP4, as set by VR4. This adjustment must be made while S1 is pressed, with a multimeter connected between TP4 and TPGND.

For voltages up to 2.5V, the time-out period in seconds is simply the measured voltage multiplied by 100. For example, a 1V setting will provide a time-out of 100 seconds.

For TP4 voltages above 2.5V, it's a bit more complicated. The procedure is as follows: divide the required time-out period in minutes by 200, then add 2.5V to this figure and adjust VR4 until the voltage at TP4 matches the calculated value.

Note that the minimum time-out above 2.5V is four minutes.

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## Table 3: Setting the time-out period

| TP4 voltage | Time-out period (approx.) | Adjustment steps | Timeout calculation (approx.) |
|---|---|---|---|
| 0-2.5V | 2-250 seconds (approx. 4 minutes) | 2 seconds | TP4 voltage x 100 seconds<br>(2 seconds miniumum) |
| 2.5-4.9V | 4-480 minutes (up to 8 hours) | 4 minutes | (TP4 voltage – 2.5V) x 200 minutes<br>(4 minutes minimum) |
| Above 4.9V | No timeout | | |

by Somnath Bera

# ARDUINO-BASED FRIDGE MONITOR AND DATA LOGGER

**Monitor the temperature and humidity in your refrigerator (or elsewhere) remotely with this Arduino-based device. It can also log these parameters over time so you can see how much the temperature and humidity vary as the compressor cycles on and off, how often the defrosting cycle occurs, how often the door is opened and so on.**

**This remote sensor/data logger** is based on a minimal Arduino-compatible circuit. As is typical for Arduinos, it uses an Atmel AVR ATmega328 microcontroller.

You could use a pre-built Arduino board such as the original Uno, the Freetronics Eleven or the Leostick, but this simpler circuit has the advantage of reduced power consumption and therefore longer battery life.

With the specified battery (6 × 2Ah NiMH AA cells), the logger will run for roughly two days continuously.

The time, temperature and humidity are shown on a remote backlit LCD, which can be up to 100m away from the logger (depending on intervening obstacles and antenna size). This data is also logged to a file on a microSD card every five seconds, along with a time stamp.

This is a good project for beginners, especially those interested in learning how to use Arduino boards, since it involves relatively few components and uses several pre-built modules.

### Circuit description

There are two circuits in this project. The first (Fig.1) is a sensor/logger/transmitter unit using an ATmega328 micro, AM2302/DHT22 single-wire temperature/humidity sensor, 433MHz transmitter and a MicroSD storage module.

A 16MHz crystal is used as the instruction clock source so the micro can keep time with reasonable accuracy. The AM2302 or DHT22 sensor (TS1) is connected to input pin 5 of IC1 (digital input #3) with a 1kΩ pull-up resistor.

The Arduino software decodes the digital signals from this sensor to get the temperature and humidity readings. These are then sent to 433MHz transmitter module TX1 from pin 4 (digital output #2).

The data is also periodically logged to the microSD card via breakout board SD1. This is driven from IC1's SPI interface consisting of pins 16 (slave select), 17 (data; master out, slave in), 18 (data; master in, slave out) and 19 (serial clock). The card detect pin is not used because the card is not normally inserted or removed during operation.

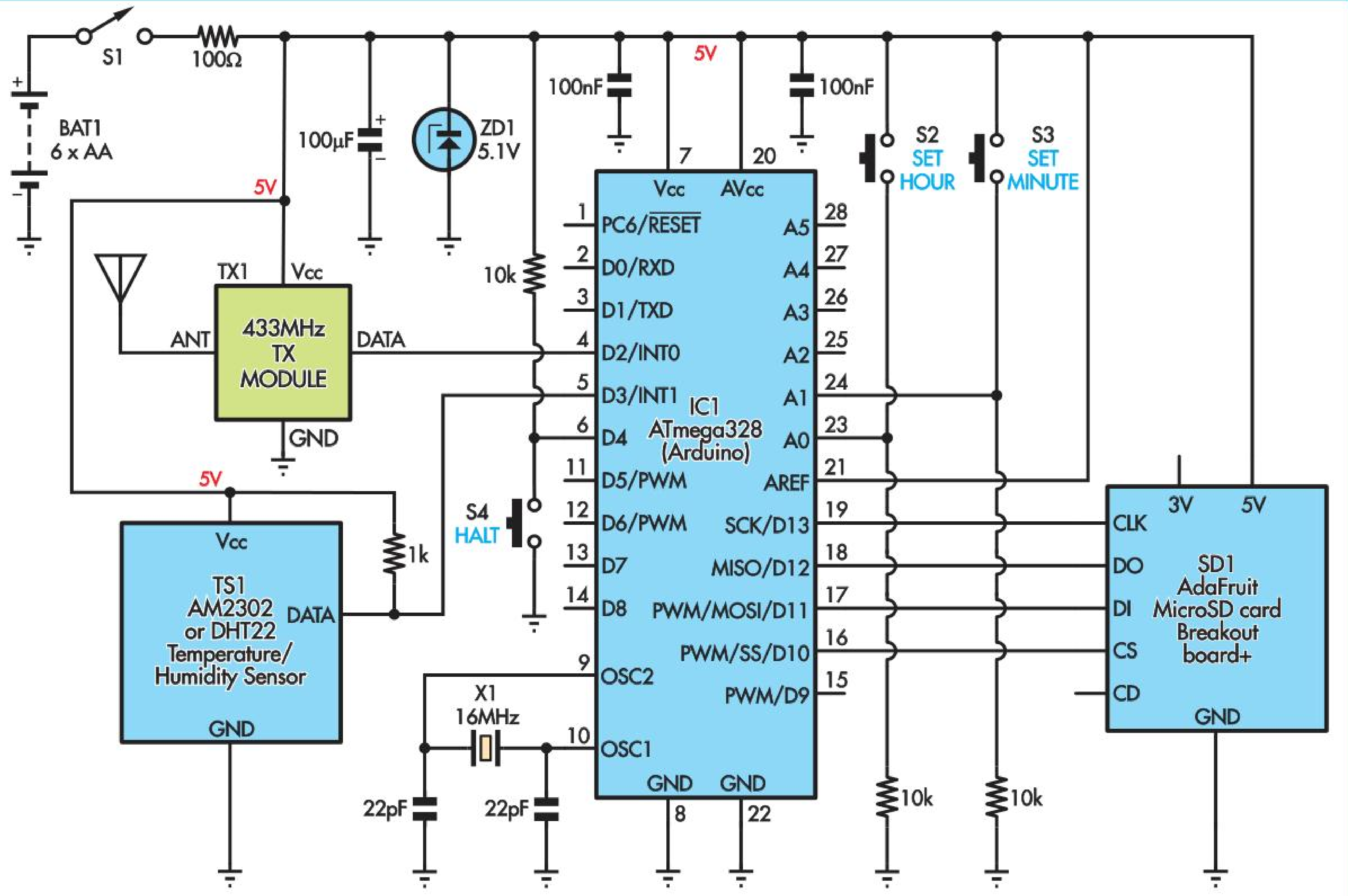

S1
100Ω
BAT1
6 x AA
+
–
100µF
ZD1
5.1V
5V
100nF
100nF
7
20
S2
SET HOUR
S3
SET MINUTE
TX1
Vcc
ANT
433MHz TX MODULE
DATA
GND
10k
Vcc
AVcc
1 PC6/RESET
2 D0/RXD
3 D1/TXD
4 D2/INT0
5 D3/INT1
6 D4
11 D5/PWM
12 D6/PWM
13 D7
14 D8
9 OSC2
10 OSC1
IC1
ATmega328
(Arduino)
A5 28
A4 27
A3 26
A2 25
A1 24
A0 23
AREF 21
SCK/D13 19
MISO/D12 18
PWM/MOSI/D11 17
PWM/SS/D10 16
PWM/D9 15
GND
GND
8
22
Vcc
TS1
AM2302
or DHT22
Temperature/
Humidity Sensor
DATA
GND
1k
S4
HALT
X1
16MHz
22pF
22pF
3V
5V
CLK
DO
DI
CS
CD
SD1
AdaFruit
MicroSD card
Breakout
board+
GND
10k
10k

**Fig.1 (above): circuit for the data logger/transmitter unit. It's based around a stripped down Arduino in the form of an ATmega328 (IC1). TS1 is used to monitor temperature and humidity. Data is transmitted in real time using 433MHz module TX1 and simultaneously logged to the microSD card via SD1.**

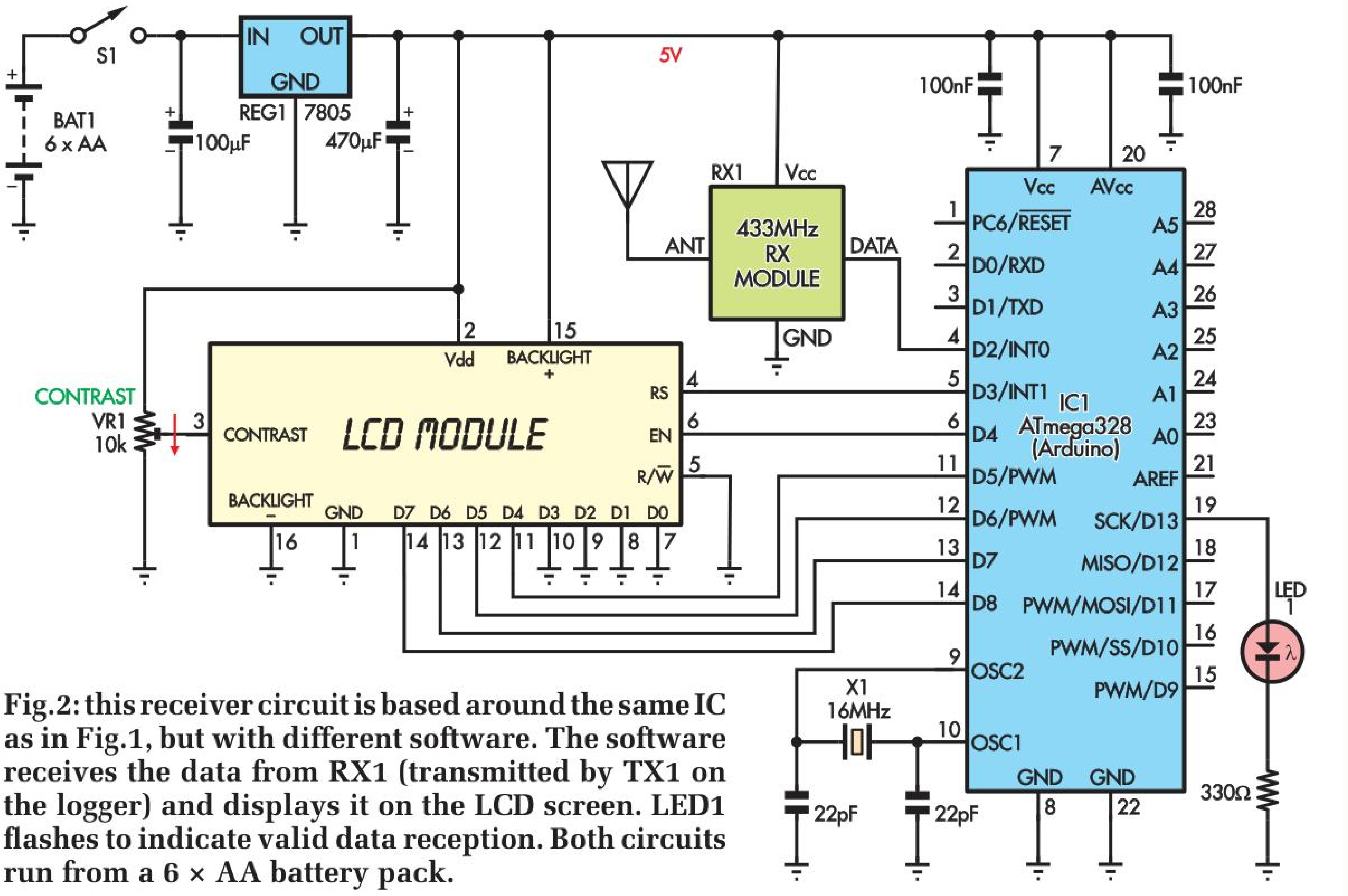

S1
BAT1
6 x AA
+
–
100µF
IN
OUT
GND
REG1
7805
470µF
5V
100nF
100nF
7
20
RX1
Vcc
ANT
433MHz RX MODULE
DATA
GND
2
15
Vdd
BACKLIGHT +
CONTRAST
VR1
10k
3
CONTRAST
LCD MODULE
RS 4
EN 6
R/W 5
BACKLIGHT –
16
GND
1
D7 D6 D5 D4 D3 D2 D1 D0
14 13 12 11 10 9 8 7
Vcc
AVcc
1 PC6/RESET
2 D0/RXD
3 D1/TXD
4 D2/INT0
5 D3/INT1
6 D4
11 D5/PWM
12 D6/PWM
13 D7
14 D8
9 OSC2
10 OSC1
IC1
ATmega328
(Arduino)
A5 28
A4 27
A3 26
A2 25
A1 24
A0 23
AREF 21
SCK/D13 19
MISO/D12 18
PWM/MOSI/D11 17
PWM/SS/D10 16
PWM/D9 15
GND
GND
8
22
X1
16MHz
22pF
22pF
LED1
λ
330Ω

**Fig.2: this receiver circuit is based around the same IC as in Fig.1, but with different software. The software receives the data from RX1 (transmitted by TX1 on the logger) and displays it on the LCD screen. LED1 flashes to indicate valid data reception. Both circuits run from a 6 × AA battery pack.**

SD cards require a 2.7-3.3V supply and the breakout board we have specified contains an onboard 3V 150mA regulator, which runs from 5V. We aren't using the 3V supply elsewhere, so that pin is left unconnected. The breakout board also has a 74HC4050 level-shifter IC onboard to translate the 5V signals from IC1 to a level suitable for the SD card (ie, 0-3V). Output signals from the SD card go directly to IC1 as its inputs will sense 3V as a high level when running from a 5V supply.

The micro's own power supply is basic; just a 100Ω series resistor and 5.1V zener diode to regulate the ~7.2-9V supply from the six AA batteries to 5V. A 3-terminal regulator could be substituted for reduced operating current. Switch S1 turns power to the circuit on and off.

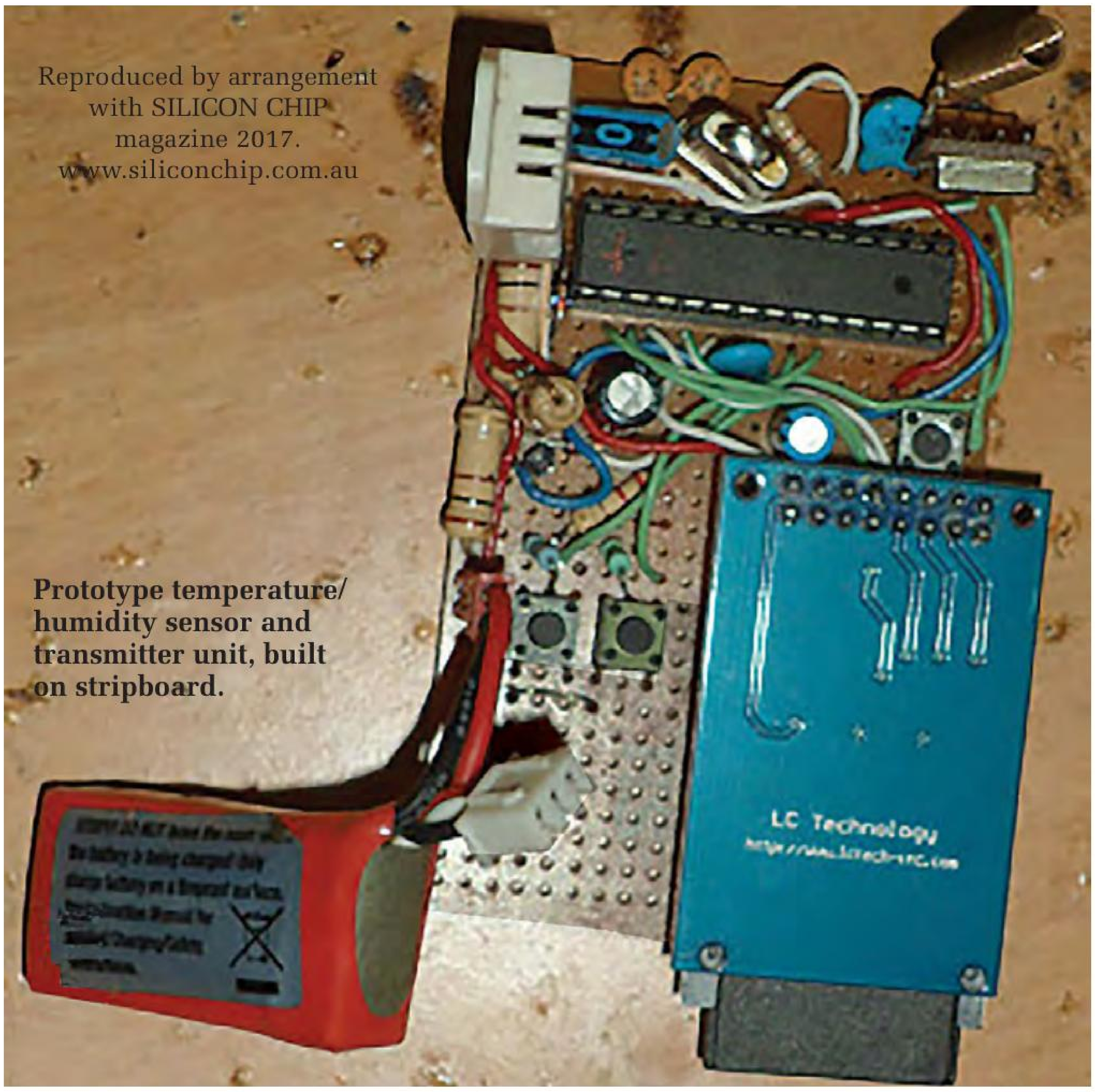
Momentary pushbuttons S2 and S3 are used to set the time for logging. The remote receiver unit shows the time being transmitted by the logger, so it's simply a matter of pressing these buttons to increment the hour/minute reading until the time on the receiver is correct. The log entry time stamps will then be correct. However, do note that the date at power-up is hard-coded into the Arduino sketch, so the micro will need to be reprogrammed each time the logger is used for the date stamps to be correct.

Pushbutton S4 is used to halt logging and the unit must be power-cycled to resume. Each time the unit powers up, it creates a new file on the SD card, to which log entries for that session are written. The temperature and humidity are logged every five seconds.

## Alternative microSD interface

SparkFun also makes a similar microSD card interface. However, it is a full-sized Arduino shield, which would be handy if you are planning to build your temperature/humidity logger using an actual Arduino board such as the Freetronics Eleven – but, it is larger and therefore consumes more power.

The only change necessary to use the SparkFun shield is to connect pins D8 and D10 together. That's because the



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**Prototype temperature/humidity sensor and transmitter unit, built on stripboard.**

SparkFun shield uses D8 as the Card Select pin. Using D10 would be a more traditional route, as this corresponds to the micro's hardware slave select pin. However, in practice, any digital I/O can be used for this purpose. Our circuit doesn't use D8, so joining them should not cause any problems.

One advantage of using the SparkFun microSD card shield is that it contains an 11 × 12 prototyping area, along with pads to make connections to each of the Arduino pins. Most or all of the required extra components will fit there, making a neat finish.

### Receiver unit

The receiver unit, (Fig.2) is also based around an ATmega328 microcontroller. The data stream from a 433MHz receiver unit is connected to pin 4 (digital input #2) and the micro drives a 16×2 alphanumeric LCD module (LCD1) in 4-bit mode. It does this via digital outputs D5-D8 (pins 11-14) for data and using digital output #3 (pin 5) to control the reset pin and digital output #4 (pin 6) to control the enable pin.

The R/W pin of the LCD module is tied to ground since there's no need to read data from it. The backlight LED circuit is connected directly across the 5V supply, while a 10kΩ trimpot provides contrast adjustment by varying the negative bias voltage at pin 3, relative to the positive supply, between 0 and –5V.

IC1 waits to receive valid data from RX1 and when it does, it updates the LCD to show the time (as reckoned by the logger), temperature (in degrees Celsius), relative humidity (percentage) and status. At the same time, LED1 is flashed to show that valid data has been received.

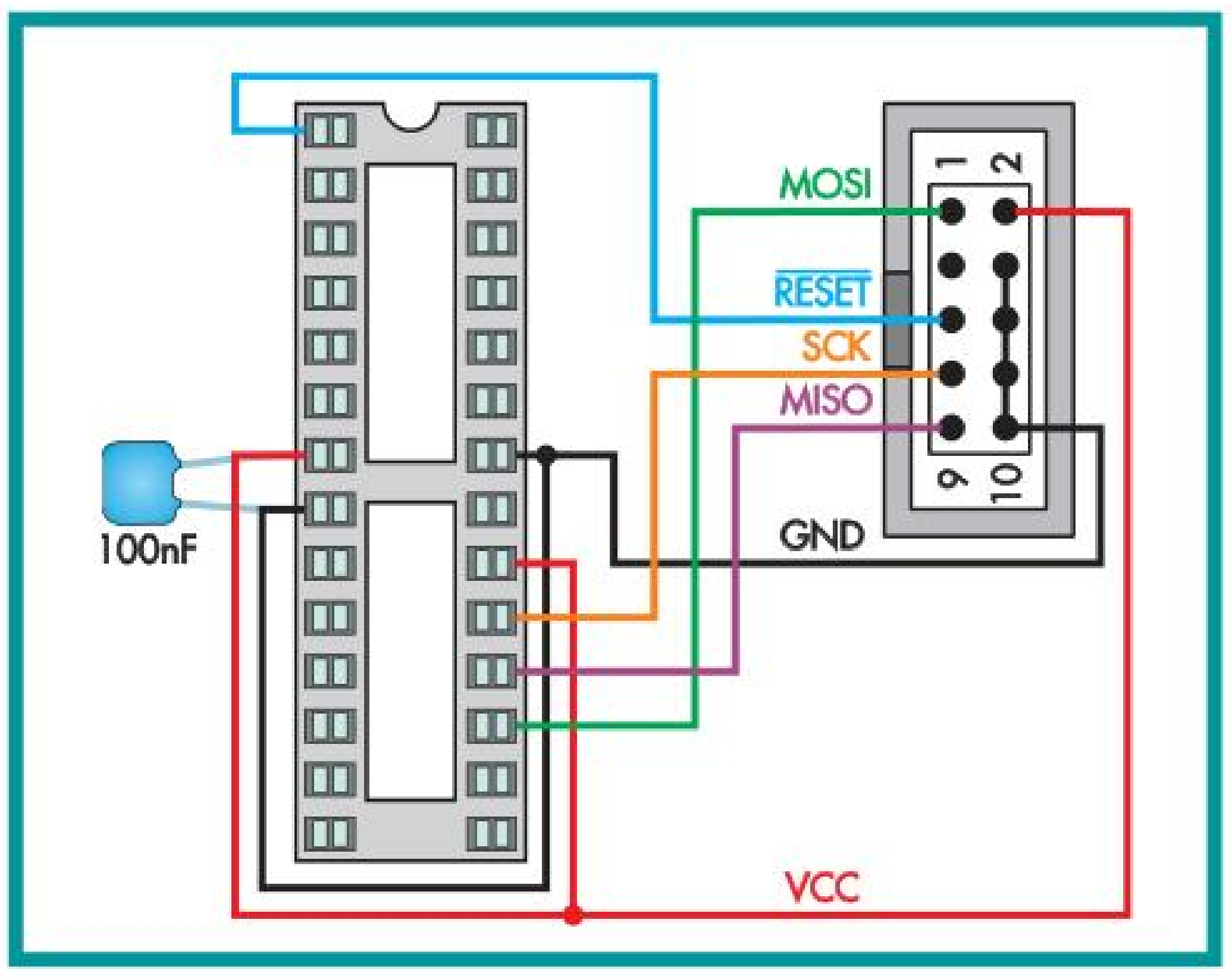


**Fig.3: to program an ATmega328 chip using an in-circuit serial programmer (ICSP), you need to make an adaptor board. Note the orientation of the 10-way IDC socket (shown in top view). You may need to add a crystal and load caps between pins 9 and 10 of the IC socket to re-program a chip that has already been programmed (see text).**

### Logging other parameters

If you want to attach other sensors to the Arduino you can do so – it has plenty of spare analogue and digital pins. You would have to modify the transmitter 'sketch' software, to sample data from the new sensor and include it in the transmitted packets and logfile. You would also need to modify the receiver sketch to decode and display the extra data (unless you simply wanted to log it).

We won't go into great detail on how to do that here, but that's the great thing about systems like Arduino – you can download the source code for this project and modify it as much as you want. If you don't know how to program an Arduino, there are plenty of books and Internet pages/forums that explain the techniques, plus of course *EPE's Teach-In 2016* series.

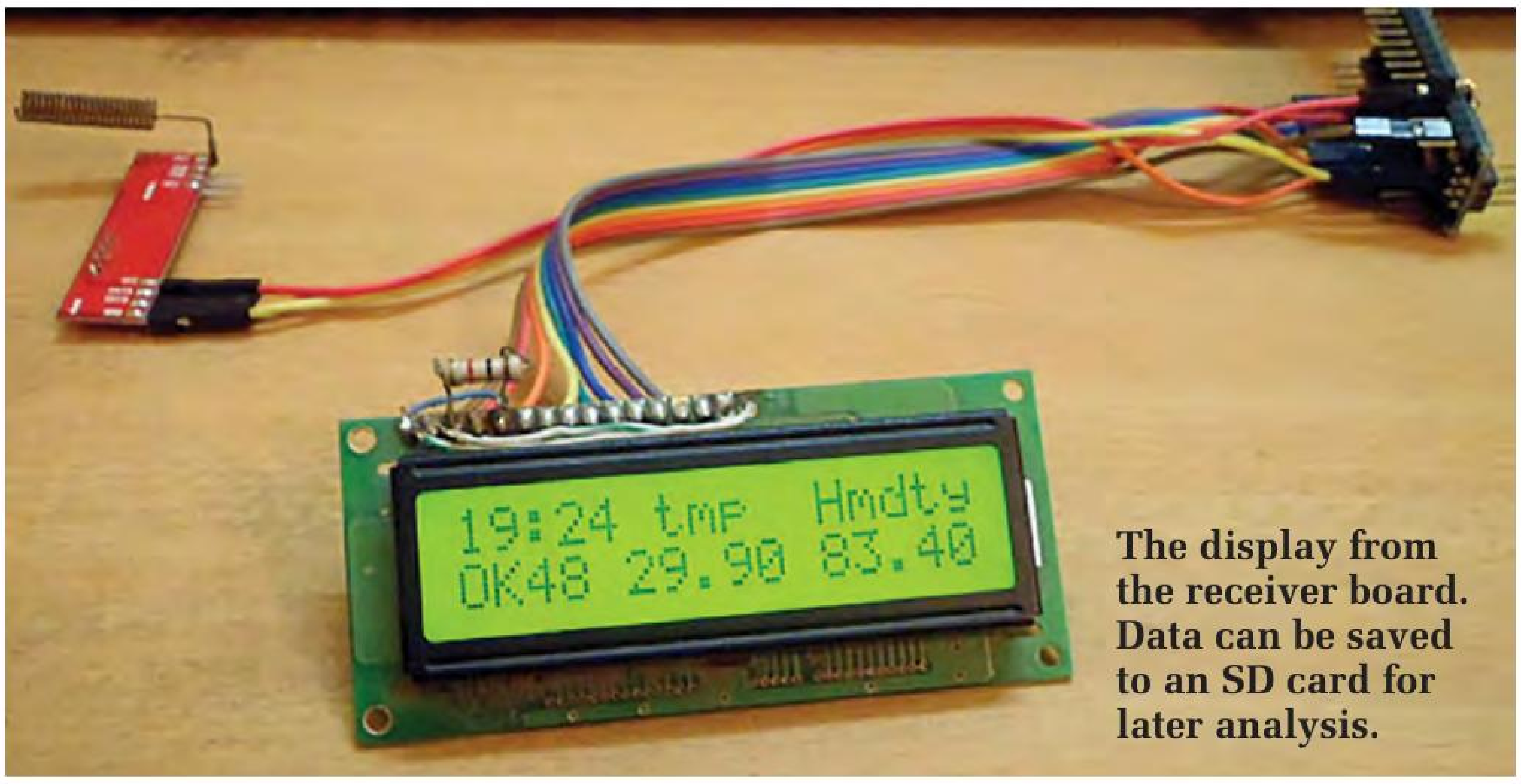
### Construction

Our prototypes were built on Veroboard using point-to-point wiring – see the adjacent photo. There are various different types of protoboard available, including an 'IC prototyping board' (which goes under various names) that mimics the connection pattern used on solderless breadboard. That would probably be a good choice for this project, although a 'donut board' (just copper rings on a 0.1-inch grid) would work too.

Construction for both units is similar. Fortunately, neither circuit is complex and most of the 'heavy lifting' is done by pre-built modules. In both cases, start by soldering in the socket for IC1. Add the crystal, ceramic capacitors and pull-up/pull-down resistors across the appropriate pins. The next step is to mount the various modules, pushbuttons and switches in convenient locations and then run insulated wires connecting their pins back to the appropriate IC pins, as shown in the relevant circuit diagrams.

Finally, wire up the power supply and prepare to connect the battery.

If you're basing your unit on a pre-built Arduino module, construction is a bit easier. If you are not using the microSD card shield with prototyping area, or the receiver unit then you can use a prototyping shield which simply plugs into the Arduino board. Like the



**The display from the receiver board. Data can be saved to an SD card for later analysis.**

microSD card shield, these also provide connection pads for the various pins which will be labelled.

### Programming the chips

For an Arduino module, the software (available at **epemag.com)** can be uploaded using a USB cable and the free Arduino IDE software from **www.arduino.cc/en/Main/Software**

In this case, once you have selected the correct target board and established communications you will be compiling and uploading the **.ino** 'sketch' file via the IDE.

However, if you are building the minimal design you will need an Atmel AVR in-circuit programmer, along with a 28-pin programming rig. AVR ICSP adaptors are available from websites like Ali Express and eBay starting at less than £2. Just search for 'avr programmer'. You may be supplied with suitable software; if not, use software such as avrdude-gui (**http://sourceforge.net/projects/avrdude-gui/**) or PonyProg (**www.lancos.com/prog.html**).

You will also need a programming adaptor for the ATmega328. You could use the *PIC/AVR Programming Adaptor* board (*EPE*, May and June 2013), or you could build one. All it takes is a small piece of Veroboard with a 28-pin socket (ideally a ZIF type) plus a 2x5 pin header. The simple circuit to achieve this is shown in Fig.3.

Note that there are a couple of tricks when programming an AVR using the ICSP method. One, you may need to set the 'fuses' as a separate step to uploading the hex file. You can determine the correct fuse settings for your chip to run an Arduino sketch here: **www.engbedded.com/fusecalc**

Second, you should set the fuses *after* uploading the hex file. This is because once the fuses are set the chip will switch to running off the external crystal and unless your programming board has a crystal (and appropriate load caps) or other clock source, you will lose communication with the chip.

The *PIC/AVR Programming Adaptor* board has a selectable clock source for this sort of situation (see that article for more details). (Note that if you are using your own adaptor, you could simply solder a crystal and pair of caps to pins 9 and 10 of the socket, as shown in Figs.1 and 2.)

Alternatively, if you don't have an AVR in-circuit serial programmer, you could get a universal programmer such as the MiniPro TL866CS and use the supplied software. These cost around £30 on Ali Express or eBay and can program just about any programmable chip, including most PICs and AVRs.

### Powering up

Regardless of how you programmed the ICs, plug in the receiver unit chip and switch on. The LCD backlight should come on but not much else will happen since the transmitter is not running yet.

If you are using the logging functionality, insert a blank microSD card into the receiver unit before powering up. Once both units are on, and after a few seconds you should see a display on the receiver LCD which will update periodically with new temperature and humidity data.

You can now use the pushbuttons on the transmitter/logger unit to set the correct time. After that it's simply a matter of placing the transmitter logger in the fridge or whatever else you want to monitor and observe the readings on the receiver LCD. You can then leave the logger to 'do its thing', retrieve it later, press S4, switch it off and remove the microSD card to check the logged data on a PC.

## Parts list: Arduino-based Temperature/ Humidity Monitor

### Logger/transmitter unit

1 piece veroboard/protoboard/stripboard
1 28-pin narrow IC socket
1 AdaFruit industries MicroSD card breakout board+ (SD1) **OR**
1 SparkFun MicroSD shield (SD1) (see text)
1 AM2302 or DHT22 temperature and humidity sensor (TS1)
1 433MHz transmitter module (TX1)
1 172mm length of stiff insulated wire (antenna for TX1)
1 six AA-cell battery holder
1 toggle or slide switch (S1)
3 momentary pushbutton switches (S2-S4)
1 16MHz crystal (X1)

**Semiconductors**

1 ATmega328 programmed with **remote_datalogger_with_time_set.ino/hex**
1 5.1V 1W zener diode (ZD1)

**Capacitors**

1 100µF 16V electrolytic
2 100nF ceramic
2 22pF ceramic

**Resistors (0.25W, 5%)**

3 10kΩ 1 1kΩ 1 100Ω

### Receiver unit

1 piece veroboard/protoboard/stripboard
1 28-pin narrow IC socket
1 16x2 alphanumeric backlit LCD module (LCD1)
1 433MHz receiver module (RX1)
1 172mm length of stiff insulated wire (antenna for RX1)
1 six AA-cell battery holder
1 toggle or slide switch (S1)
1 16MHz crystal (X1)

**Semiconductors**

1 ATmega328 microcontroller programmed with **fridge_temp_receiver_lcd_with_data_logger_time_set.ino/hex**
1 7805 5V regulator (REG1)
1 LED (LED1)

**Capacitors**

1 470µF 10V electrolytic
1 100µF 16V electrolytic
2 100nF ceramic
2 22pF ceramic

**Resistors**

1 330Ω 0.25W 5%
1 10kΩ trimpot

# Ingenuity Unlimited

**Our regular round-up of readers' own circuits**

We pay between £10 and £50 for all material published, depending on length and technical merit. We're looking for novel applications and circuit designs, not simply mechanical, electrical or software ideas. Ideas must be the reader's own work and **must not have been published or submitted for publication elsewhere**. The circuits shown have NOT been proven by us. **Ingenuity Unlimited** is open to ALL abilities, but items for consideration in this column should be word-processed, with a brief circuit description (between 100 and 500 words maximum) and include a full circuit diagram showing all component values. **Please draw all circuit schematics as clearly as possible.** Email your circuit ideas to: **fay.kearn@wimborne.co.uk**.

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## Sine/square wave oscillator 10-100kHz

### Basic requirements

**ANALOGUE** sine wave oscillators are capable of generating waveforms of acceptably low distortion provided certain basic requirements are adhered to.

First and foremost, the gain of the amplifier has to be accurately controlled and to achieve this the output voltage has to be monitored and used to adjust the gain upwards or downwards as required.

In this case, a JFET is used as a variable resistor, but to keep it in its ohmic region it is necessary to ensure its Vds is maintained below 1V.

The choice of components is important and some values are quite critical. The situation is made more difficult where the oscillator has a frequency range of about 10,000:1, as is the case here.

The other problem is that most readily available capacitors have a tolerance of ±10%, although there are some at ±5%. It's a case of hunting around within your budget.

Trying to obtain ganged variable resistors (VR1,2) where the resistance from both tracks is equal at all settings is well-nigh impossible. However, an audio 100kΩ twin-gang linear potentiometer works well enough in this case, albeit somewhat jerky in operation.

### Circuit detail

The oscillator uses a dual channel NE5532N IC, which can

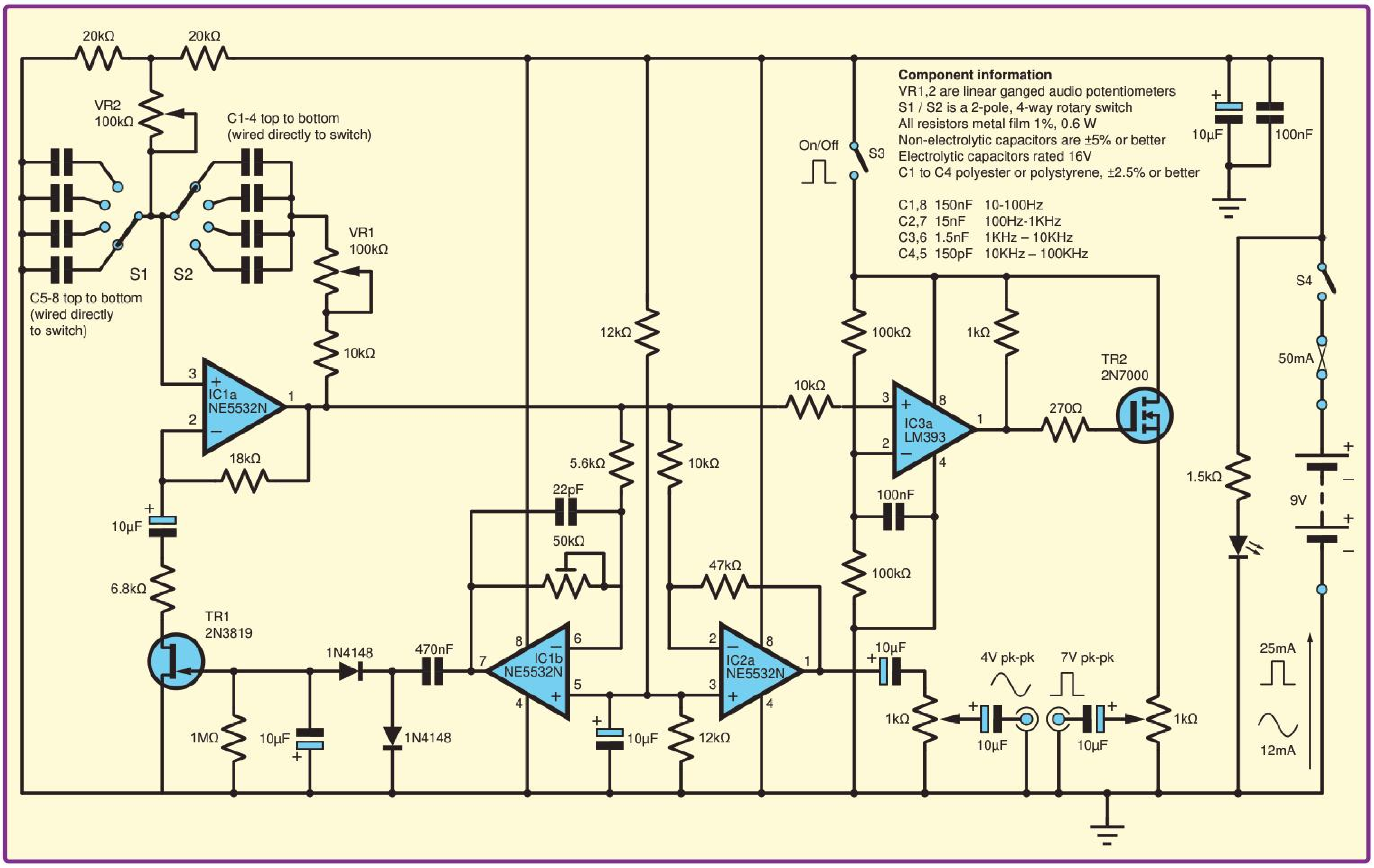
Component information
VR1,2 are linear ganged audio potentiometers
S1 / S2 is a 2-pole, 4-way rotary switch
All resistors metal film 1%, 0.6 W
Non-electrolytic capacitors are ±5% or better
Electrolytic capacitors rated 16V
C1 to C4 polyester or polystyrene, ±2.5% or better
C1,8 150nF 10-100Hz
C2,7 15nF 100Hz-1KHz
C3,6 1.5nF 1KHz – 10KHz
C4,5 150pF 10KHz – 100KHz
20kΩ
20kΩ
VR2 100kΩ
C1-4 top to bottom (wired directly to switch)
C5-8 top to bottom (wired directly to switch)
S1
S2
VR1 100kΩ
10kΩ
IC1a NE5532N
18kΩ
10μF
6.8kΩ
TR1 2N3819
1MΩ
10μF
1N4148
1N4148
470nF
12kΩ
5.6kΩ
22pF
50kΩ
IC1b NE5532N
10μF
10kΩ
47kΩ
12kΩ
IC2a NE5532N
On/Off
S3
10kΩ
100kΩ
1kΩ
IC3a LM393
100nF
100kΩ
270Ω
TR2 2N7000
10μF
1kΩ
4V pk-pk
7V pk-pk
10μF
10μF
1kΩ
10μF
100nF
S4
50mA
1.5kΩ
9V
25mA
12mA

*Fig.1. Sine/square wave oscillator with 10,000:1 frequency range*

work to 100kHz – do use this op amp.

The capacitors, resistors and switching around IC1a pins 1 and 3 and ground provide a means of tuning the circuit to the desired frequency.

The 1Vpk-pk output signal is picked off at IC1a, pin 1 and fed to inverting amplifier IC1b, which is adjusted with the 50kΩ trimmer to a gain of around four, such that the waveform at its output (pin 7) is roughly 4Vpk-pk. This 50kΩ trimmer also caters for the varying characteristics of different JFETs.

This AC voltage is fed via the 470nF capacitor to the two diodes and 10µF smoothing capacitor, with 1MΩ bleed resistor. The voltage appearing at the gate of the JFET is therefore about –3.5V, and this provides the correct resistance across the JFET, which together with the 18kΩ and 6.8kΩ resistors keeps the gain at about three, with an output voltage of 1Vpk-pk at pin 1.

The 22pF shunt capacitor across the 50kΩ trimmer is essential to prevent spurious oscillation and its value is reasonably critical.

The 10µF capacitor between pin 5 (IC1,2) and ground maintains the amplitude stability of the waveform. 10µF and 100nF capacitors decouple the power supply.

The LM393 comparator converts the sinewave output to a square wave, and the 2N7000 N-channel MOSFET acts as a high-speed buffer, providing a low impedance output.

### Some 'tweaking' possibilities

Due to the spread of component tolerances and stray capacitance it is possible that a frequency as low as 10Hz or as high as 100kHz might not be quite achieved.

For example, if only 90kHz is obtained then it is possible to reduce the value of the 10kΩ resistor IC1a to pin1 to say 9kΩ by placing a 100kΩ resistor in parallel with it. It will then be necessary to reduce both 20kΩ resistors to 18kΩ, as these are effectively in parallel.

If the lowest frequency of 10Hz cannot be achieved then capacitors can be placed in parallel with both 150nF capacitors, say in the region of 10-32nF.

### Power Supply

A full 9V DC supply is required, and with this limited headroom a 9.6V NiMH battery is preferable, because the voltage from ordinary alkaline batteries tends to sag after a relatively short period. Alternatively, a regulated 9-12V DC supply can be used.

### Construction

This is left to the constructor. Wiring should be kept short. If stripboard is used, careful layout and the removal of appropriate sections of the copper track can help to reduce stray capacitance.

### Testing

An oscilloscope and frequency counter are useful for calibration and to ensure the waveforms are of good quality. To display the square wave the scope should be set to DC input and the probe to the x10 range.

**Duncan McKellar**

## Heat trick

**OVER THE** years, I have designed several electronic 'conjuring tricks'. The most popular was my *ESP Conjuring Trick* – a fairly large circuit that pulsed a high voltage through the fingers. However, I have long had in mind a more basic (and safer) version of this trick, and here it is.

This circuit informs the conjurer what is inside a box through (ow!) heat. To describe it simply, the conjurer invites someone in the audience to place a peg in a box – either red or blue – and then to close the box. The conjurer places his or her hands on the box (touching crucial studs), pauses for a while, then announces which colour peg is in the box.

### The circuit

Power MOSFET TR1 conducts and R3, a 2W resistor heats up when both pin 1 and pin 2 of CMOS IC1a go low. Pin 1 goes low when two moist (licked) fingers touch both studs A and B on the outside of the box. Pin 2 goes low when a magnet is brought near magnetic reed switch S1. When both pins are low, R3 heats up. It will heat up – or not – depending on whether a specially modified peg with a magnet hidden inside is chosen, which will close S1.

R3 is the vital part – a 2W 43Ω resistor. Since the circuit runs off 12V, R3 is underrated, so heats up when TR1 conducts. R3 is closely joined to Stud C on the outside of the box, so that heat flows easily to the stud, and is detected by a finger. Note, however, that the characteristics of fingers and resistors vary, and the value of R3 may need to be increased or decreased to vary the heat, or another 2W resistor may be tried. Some care will be needed in placing studs and in routing wires (note that hinges can be used to conduct current).

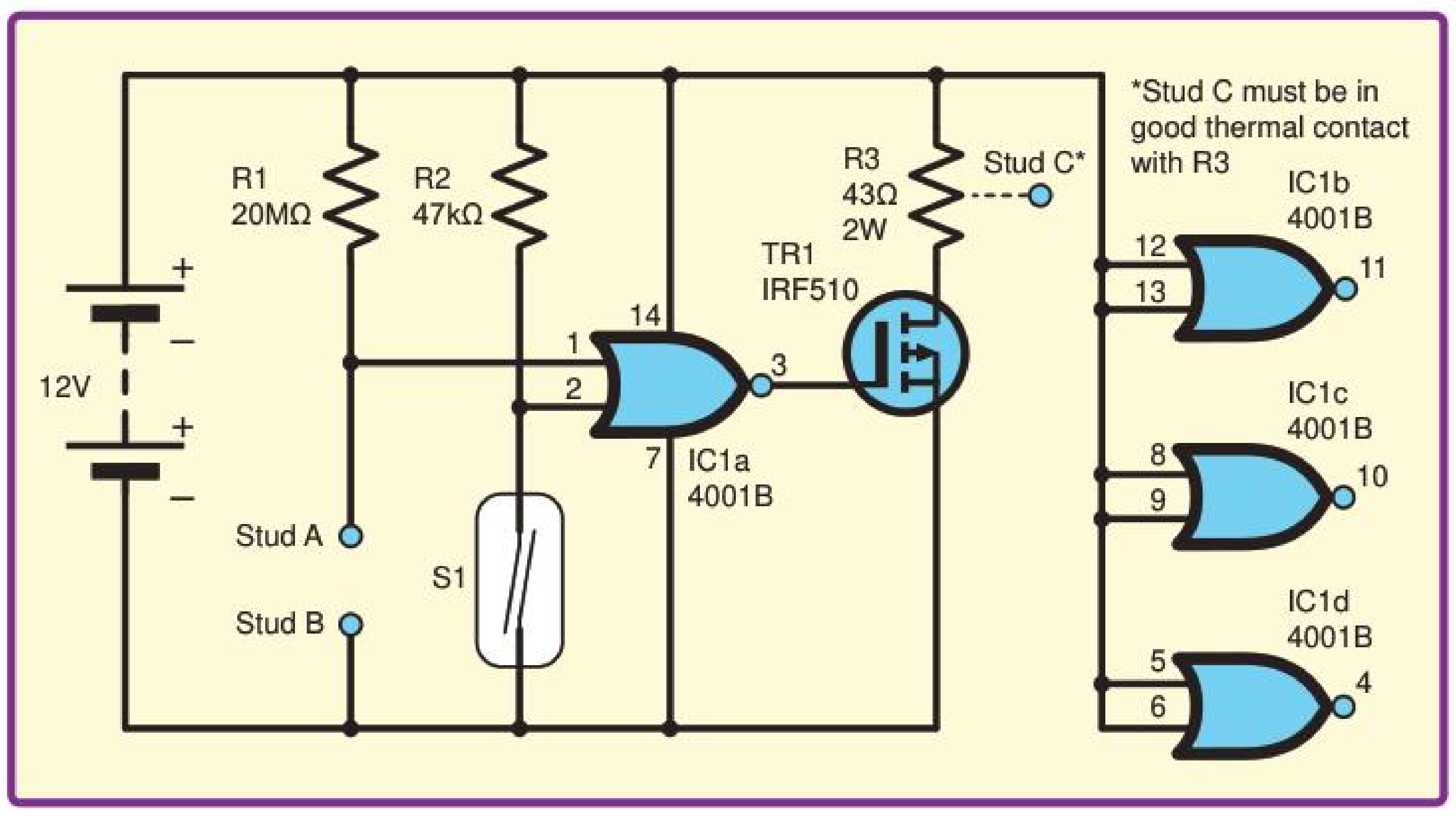

Fig.2. Build this electronic conjuring trick!

If this trick is well made, it will be inscrutable! One could also use the spare gates (IC1b to IC1d) to make the trick more sophisticated, with up to three more circuits and three more hot studs. Note that Stud B could be common to all four circuits, as it is connected to 0V.

Studs A and B should be touched only until Stud C heats up. If Stud C were permanently heated, then R3 would probably burn out. Also, since R3 chews up current, a good 12V battery or battery pack is required (say, six AA batteries). An on-off switch may be inserted in the circuit if desired – however, this should not be visible. Alternatively, the battery clip could simply be unclipped when the circuit is not in use.

### Component notes

R1 and R2 are ordinary 0.25W resistors; S1 is a normally open magnetic reed switch.

**Rev Thomas Scarborough,**
**Cape Town, South Africa**

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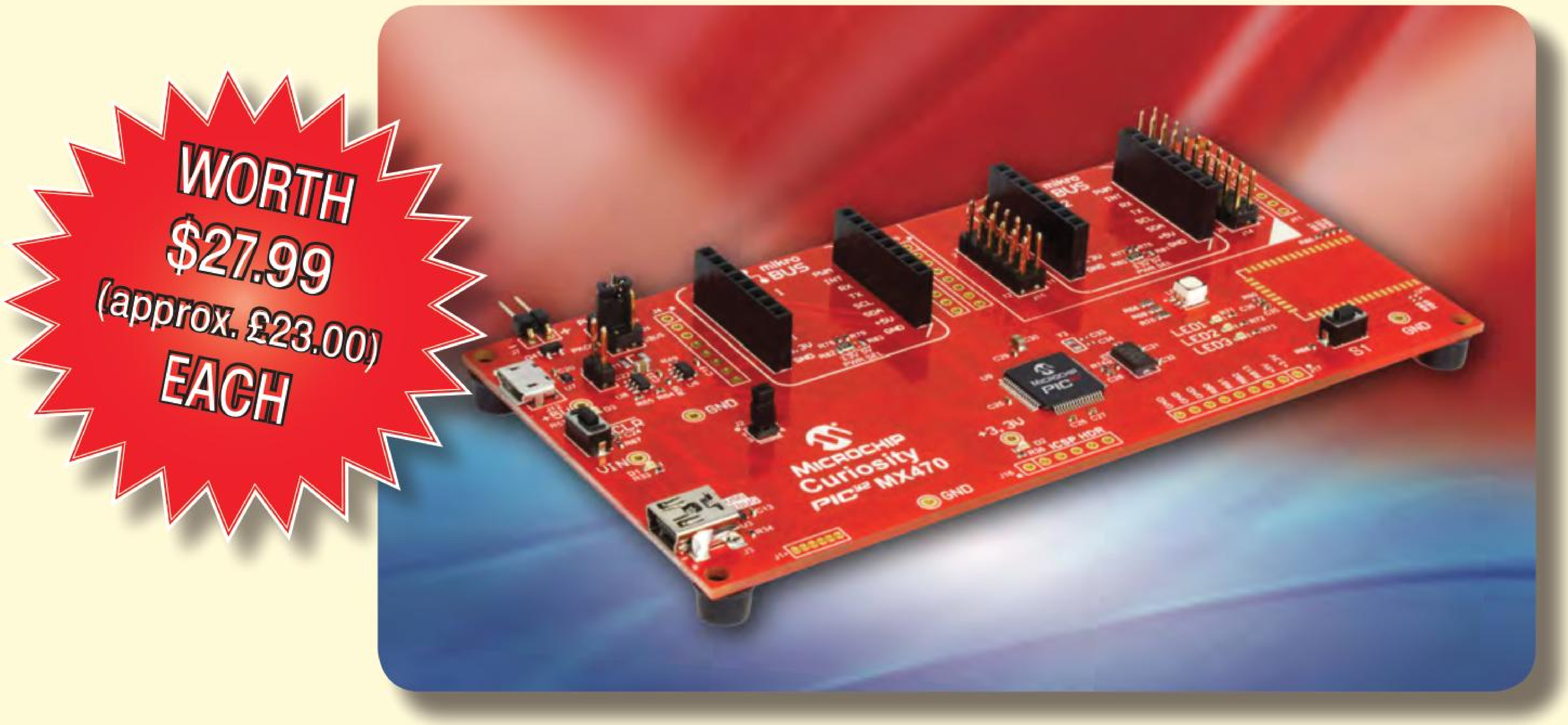

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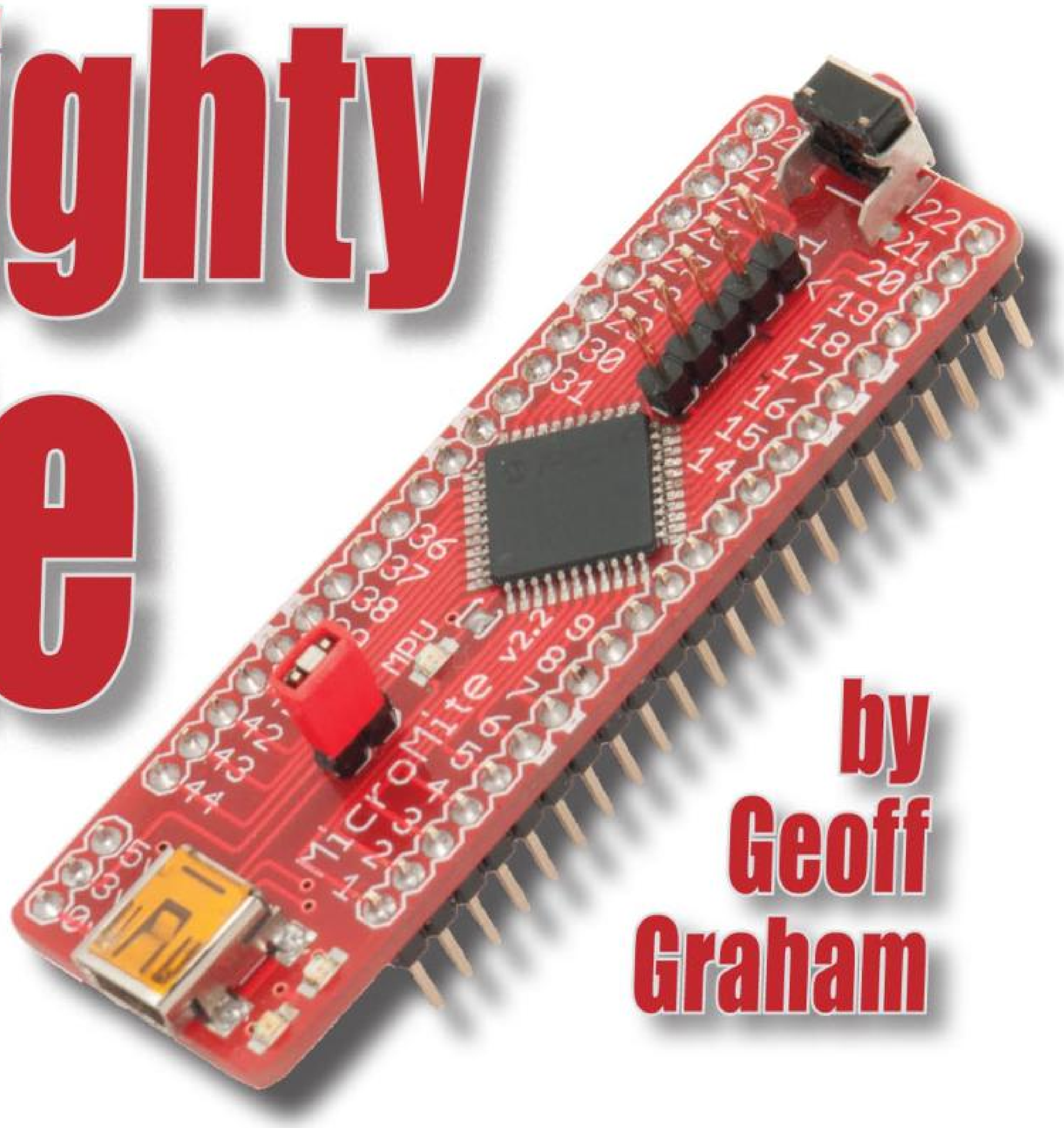
# Meet the mighty Micromite

## Part 2: Input/output and special devices

by Geoff Graham



***The Micromite is an amazing device. A low-cost microcontroller programmed in a Microsoft-compatible version of BASIC with floating point, arrays and extensive string handling. The Micromite can interface to a variety of devices including touch-sensitive LCD panels and a host of sensors for temperature, humidity, GPS and more. Even better, the microcontroller only costs a couple of pounds and the BASIC interpreter is free. Available in a user-friendly 28-pin package, the Micromite makes a great controller for your heating system, lighting manager or whatever else your imagination can dream up.***

### Introduction

In this article we will describe some of the special features of the Micromite and how you can control its input/output pins and special devices like LCD screens.

But before we do that you need to know how to get a program into the Micromite in the first place. You have a number of choices when it comes to this, you can type it into a desktop (or laptop) computer and transfer it to the Micromite, or you can use the editor that is built into the Micromite.

In the following, we will give you a high-level description of what you can do with the Micromite. However, for a detailed description, you should refer to the *Micromite User Manual*, which can be downloaded for free along with the firmware from the *EPE* or author's website: **http://geoffg.net/micromite.html**

If you prepare the program on your desktop computer you can transfer it to the Micromite using either the AUTOSAVE or XMODEM commands. This depends on you having a terminal emulator running on your desktop machine and connected to the console of the Micromite. How to do this was fully described last month in *Meet the Mighty Micromite – Part 1: Introduction*.

The AUTOSAVE command puts the Micromite into a mode where anything received on the console will be saved to the program memory. This means that you can simply copy the text and paste it into the terminal emulator (eg, Tera Term), which will send it to the Micromite. From the Micromite's perspective, pasting text into the terminal emulator is the same as if a high-speed typist was typing in the program.

Tera Term is a free program that can be downloaded from: **http://tera-term.en.lo4d.com**

To terminate the `AUTOSAVE` command you need to type `CTRL-Z` in the terminal emulator and the Micromite will save the program to Flash memory and return to the command prompt.

The `XMODEM` command is a little more sophisticated; it uses the XModem protocol to transfer the data, including an integrity check. The full command is:

```
XMODEM RECEIVE
```

This instructs the Micromite to look for an XModem connection on the console. After running this command you then instruct your terminal emulator to send the file using the XModem protocol. In Tera Term this is done by using the following menu selection:

```
File->Transfer->XMODEM->Send
```

When the file has been sent, the Micromite will save it in program memory and return to the command prompt.

### MMEdit

Another convenient method of creating programs and sending them to the Micromite is to use MMEdit. Jim Hiley from northern Tasmania in Australia wrote this program, which can be installed on a Windows or Linux computer. It allows you to edit your program on your PC then, with a single button click, transfer it to the Micromite for testing.

MMEDIT is easy to use with colour-coded text, mouse-based cut and paste and many more useful features such as bookmarks and automatic indenting. Because the program runs on your PC you can save and load your programs to and from the computer's hard disk.

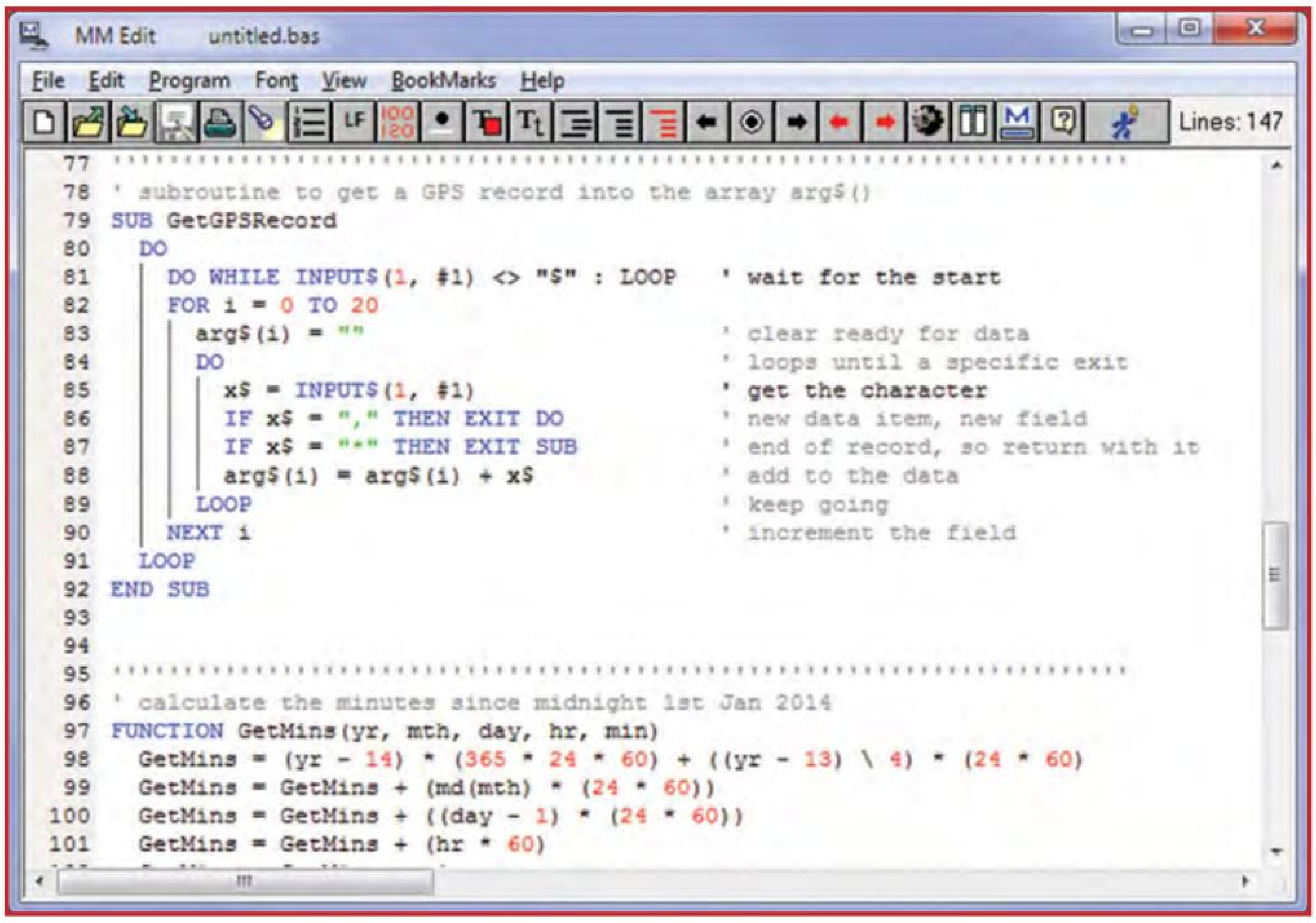
Fig.1 shows a screen shot of MMEDIT in action. The most important feature is the right-hand button on the tool bar (the icon of a running man). When you click on this button the program will be immediately transferred to your Micromite using the XModem protocol.

Following the transfer, a window will be automatically opened and connected to the Maximite's console, where you can run and test your program. If it has an error or needs tweaking it is very easy to go back to the editor, make the change and transfer it to the Micromite again.

MMEDIT can be downloaded from Jim's website at: **www.c-com.com.au/MMedit.htm** – it's free, although he'd appreciate a small donation.

### Built-in editor

The Micromite also has its own built-in editor. This relies on you using a terminal emulator that is VT100 compatible (ie, Tera Term) on your desktop computer. To invoke the editor you use the `EDIT` command. When it is first run the editor will display an empty screen with a help line at the bottom. You can then just type in your program – Fig.2 shows an example.



```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' subroutine to get a GPS record into the array arg$()
SUB GetGPSRecord
  DO
    DO WHILE INPUT$(1, #1) <> "$" : LOOP    ' wait for the start
    FOR i = 0 TO 20
      arg$(i) = ""                          ' clear ready for data
      DO                                    ' loops until a specific exit
        x$ = INPUT$(1, #1)                  ' get the character
        IF x$ = "," THEN EXIT DO            ' new data item, new field
        IF x$ = "*" THEN EXIT SUB           ' end of record, so return with it
        arg$(i) = arg$(i) + x$              ' add to the data
      LOOP                                  ' keep going
    NEXT i                                  ' increment the field
  LOOP
END SUB


''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' calculate the minutes since midnight 1st Jan 2014
FUNCTION GetMins(yr, mth, day, hr, min)
  GetMins = (yr - 14) * (365 * 24 * 60) + ((yr - 13) \ 4) * (24 * 60)
  GetMins = GetMins + (md(mth) * (24 * 60))
  GetMins = GetMins + ((day - 1) * (24 * 60))
  GetMins = GetMins + (hr * 60)
```

*Fig.1. MMedit – write programs on a PC and then transfer them to Micromite*

If you are used to an editor like Notepad in Windows you will find that the operation of this editor is familiar. The arrow keys will move your cursor around in the text, while the home and end keys will take you to the beginning or end of the line. Page up and page down will do what their titles suggest.

The delete key will delete the character at the cursor and backspace will delete the character before the cursor. About the only unusual key combination is that two home key presses will take you to the start of the program and two end key presses will take you to the end.

At the bottom of the screen the status line lists the various function keys used by the editor and their action. In more details these are:

| | |
|---|---|
| ESC | This will cause the editor to abandon all changes and return to the command prompt with the program memory unchanged. |
| F1: SAVE | Save the program to program memory and return to the command prompt. |
| F2: RUN | Save the program to program memory and immediately run it. |
| F3: FIND | Prompt for the text that you want to search for. When you press enter the cursor will be placed at the start of the first entry found. |
| SHIFT-F3 | After you have used the search function once you can repeatedly search for the same text by pressing SHIFT-F3. |
| F4: MARK | *see F5 description* |
| F5: PASTE | These functions enable you to copy, cut and paste text. The *Micromite User Manual* goes into more detail. |

The editor is a very productive method of writing a program. With it, you can write your program on the Micromite, then, by pressing the F2 key, you can save and run the program. If your program should stop with an error you can press the function key F4, which will run the editor again with the cursor positioned at the line that caused the error.

After you have corrected the error you can rerun the program by pressing the F2 key again. As a result the edit/run/edit cycle is very fast and you can quickly build an error-free program.

## Input/output

The great feature of the Micromite is that it has a wide range of commands that you can use to control the external world from within your BASIC program. You can simply read the value of an I/O pin or set it as an output, either high or low – you can also read voltages, frequency, temperature, humidity, distance and more, while also reacting to infrared control signals or interfacing to switches and keypads.

By default (ie, on power up) the I/O pins on the Micromite will default to not configured. They are high impedance and neither an input nor an output. To use an I/O pin you must first specify what it is with the SETPIN command. For example, SETPIN 3, DOUT will set pin 3 to be a digital output. You can then use the PIN command to set it either high or low. For example, PIN(3)=0 will set it low and PIN(3)=1 will set it high (ie, 3.3V). The following are the functions that an I/O pin can perform:

| | |
|---|---|
| DIN | Digital input |
| DOUT | Digital output |
| AIN | Analogue input (ie, measure voltage) |
| FIN | Frequency measurement |
| PIN | Period measurement |
| CIN | Count the number of pulses |

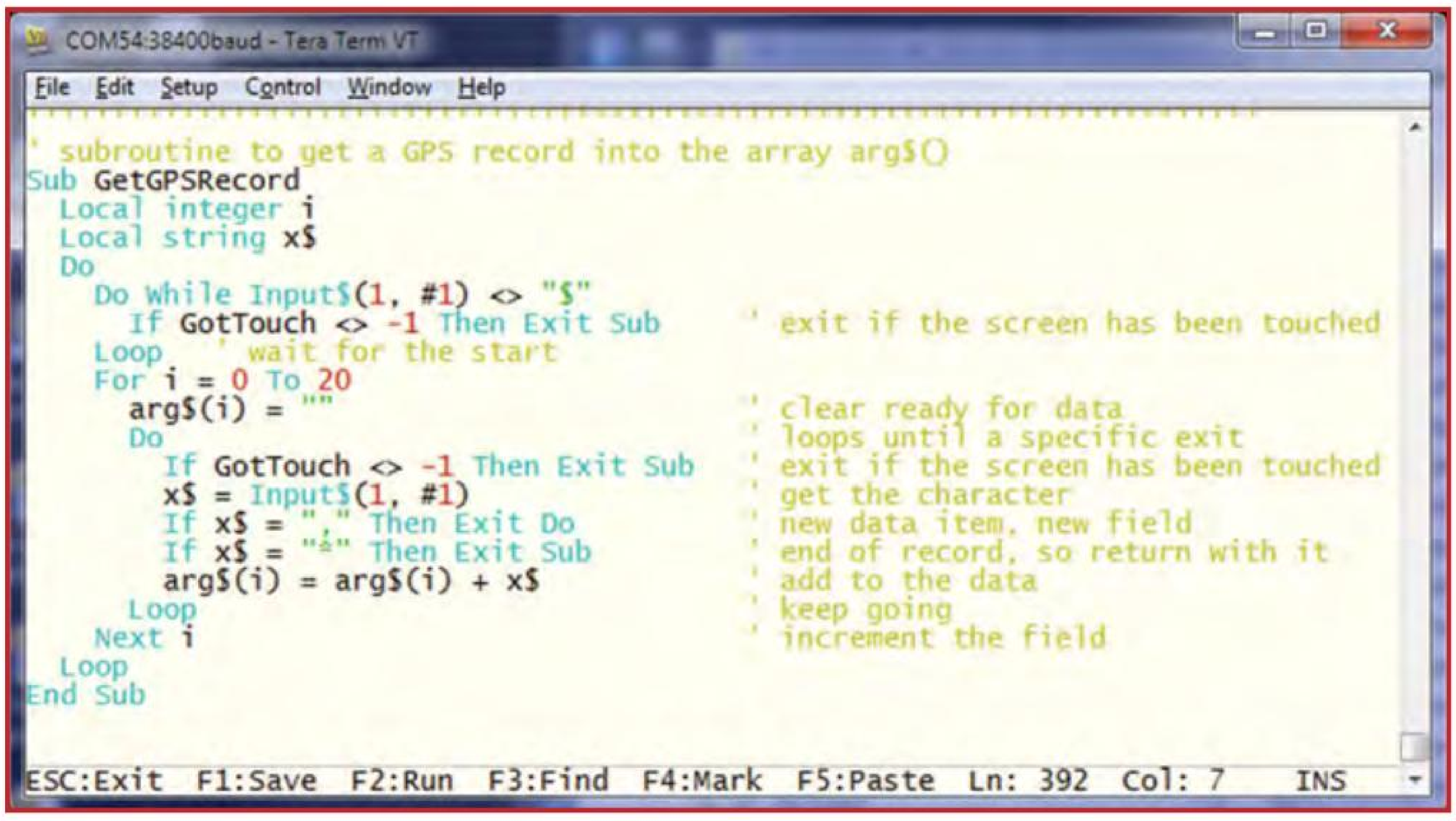
As another example, if you used the command SETPIN 3, AIN, Pin 3 would become an analogue input capable of measuring voltage between zero and 3.3V. MMBasic makes this easy for you as it takes a number of readings to reduce noise then scales the value to volts. If you connected a single-cell battery to this input and used the command PRINT PIN(3) then you could expect to see something like 1.56 on the screen, which is the voltage of the battery cell. Depending on the Micromite that you are using you can have over a dozen analogue inputs, which is similar to a 12-input digital voltmeter.

The frequency input function operates in a similar way. The command SETPIN 15, FIN would set pin 15 to be a frequency-measuring input. The Micromite can measure frequency up to 200kHz and the PIN(15) function would then return the frequency in Hz.

## Other I/O commands

There are many other I/O-oriented commands that are available to you. For example the PULSE command will generate a pulse on an I/O pin. The width of this pulse can range from microseconds to months, with longer pulses (3ms or more) being run in the background so that your BASIC program can continue doing useful work.

A similar function is the PULSIN function, which will measure the pulse width of a signal on an input pin. It can measure the width of a pulse from 1μs


COM54:38400baud - Tera Term VT
File Edit Setup Control Window Help

```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' subroutine to get a GPS record into the array arg$()
Sub GetGPSRecord
  Local integer i
  Local string x$
  Do
    Do While Input$(1, #1) <> "$"
      If GotTouch <> -1 Then Exit Sub     ' exit if the screen has been touched
    Loop    ' wait for the start
    For i = 0 To 20
      arg$(i) = ""                        ' clear ready for data
      Do                                  ' loops until a specific exit
        If GotTouch <> -1 Then Exit Sub   ' exit if the screen has been touched
        x$ = Input$(1, #1)                ' get the character
        If x$ = "," Then Exit Do          ' new data item, new field
        If x$ = "*" Then Exit Sub         ' end of record, so return with it
        arg$(i) = arg$(i) + x$            ' add to the data
      Loop                                ' keep going
    Next i                                ' increment the field
  Loop
End Sub

ESC:Exit  F1:Save  F2:Run  F3:Find  F4:Mark  F5:Paste  Ln: 392  Col: 7    INS
```

*Fig.2. The* EDIT *command brings up the Micromite's own editor*

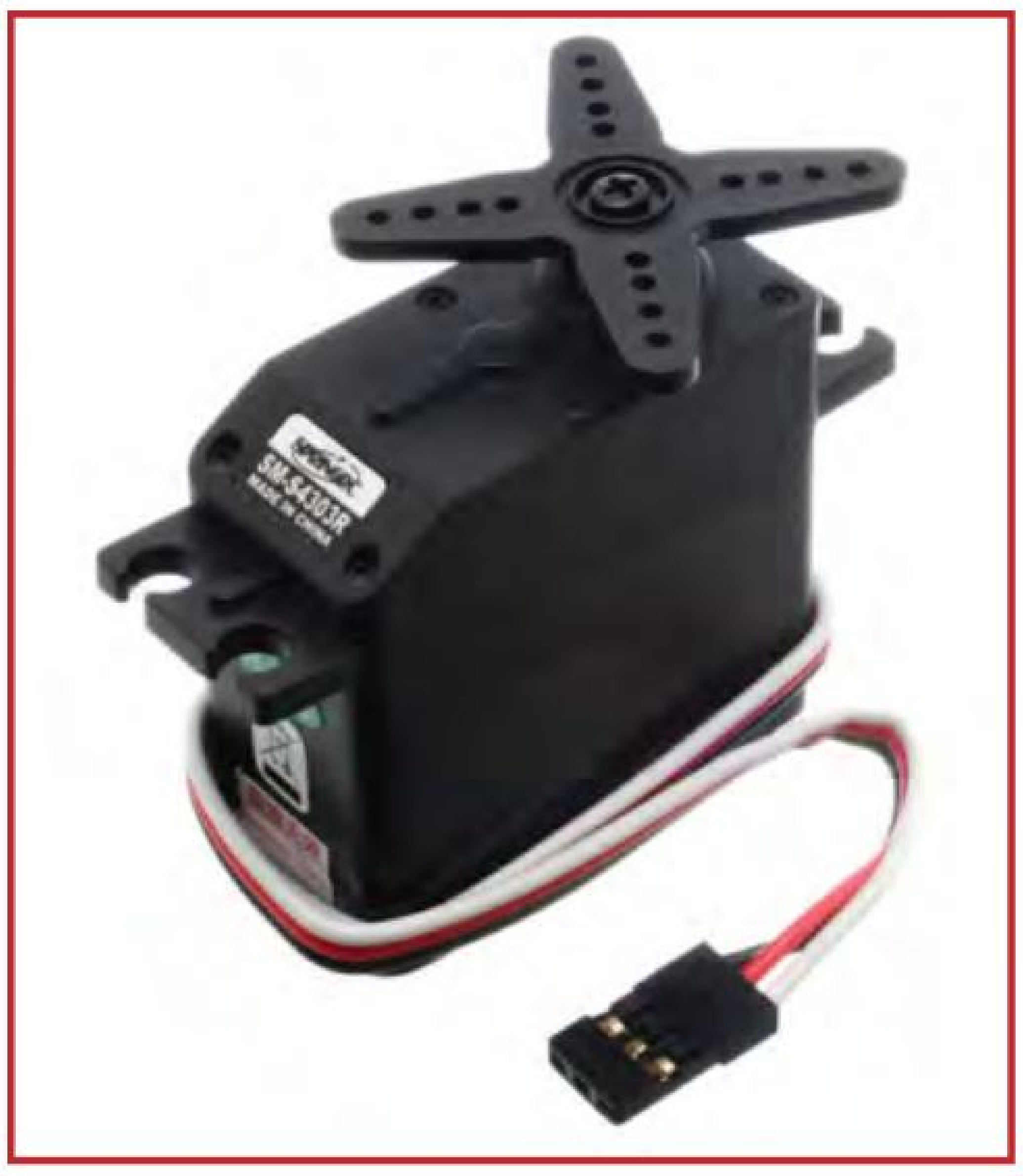


*Fig.3. Five of Micromite's I/O pins can generate PWM to drive servos*

to 1s with 0.1µs resolution and has a timeout so that your program does not hang if there is a non-existent input.

Another handy feature is the PORT command and function. This allows you to update a large number of I/O pins in parallel with a single command or input data from a number of pins in parallel. This function is useful when you are communicating via a parallel input or output such as a printer or memory chip.

### PWM and servo outputs

Five I/O pins can generate PWM or servo signals. 'PWM' stands for 'pulse-width modulation' and the signal generated by MMBasic is a constant square wave output with a specified duty cycle and frequency. For example the command `PWM 2, 1000, 20` will set the PWM 2A output to 1kHz with a duty cycle of 20%. By varying the duty cycle (the ratio between the positive pulse and the negative pulse) your program can generate a synthesised voltage that can be set to various levels to control devices that need an analogue input.

The Micromite can use the PWM outputs to control servos. Servos are a motor, often with integrated gears and a control system that allows the position of the shaft to be precisely controlled. The Micromite can simultaneously control up to five servos.

Standard servos, as shown in Fig.3, allow the shaft to be positioned at various angles, usually between –90 and +90 degrees. Continuous rotation servos allow the rotation of the shaft to be set to various speeds. The position of the servo is controlled by a pulse which is repeated every 20ms. Generally, a pulse width of 0.8ms will position the rotor at –90°, a pulse width of 2.2ms will position it at +90° and 1.5ms will centre the rotor. Depending on their size, servos can be quite powerful and provide a convenient way for the Micromite to control the mechanical world.

### Communications

A powerful feature of the Micromite is the range of communications protocols that it supports. These are integrated into the BASIC language and are easy to use so you can conveniently connect to test equipment, other ICs or sensors.

The list of communications protocols covers serial (TTL, RS232 or RS485), I$^2$C, SPI and 1-wire. Serial is used to communicate with test equipment and GPS modules, I$^2$C and SPI are mostly used to talk to other chips or sensors and 1-wire is a speciality protocol for certain types of sensors. As mentioned before, we will not go into each protocol in detail; just provide enough information for you to understand how they work. You can then refer to the *Micromite User Manual* for the full details.

### Serial communications

The Micromite has two serial ports, one can operate up to 282,000 baud while the second will work up to 19,200 baud. The first port is particularly flexible and can use TTL signalling levels (ie, 0 to 3.3V) or work with RS232 signals. It can also drive RS485 circuits and generate the required EN signal. To open a serial port you use the command:

```
OPEN "COMx:" as #n
```

Where `COMx` can be COM1 for the first serial port or COM2 for the second. `#n` is the reference number of the serial channel and can be any number between #1 and #10.

To send something out of the serial port you use the `PRINT` command; for example:

```
PRINT #4, "Hello"
```

This will send a series of characters spelling 'Hello' out of the serial port opened as #4. To receive characters from a serial port you can use a number of commands or functions but the best is the `INPUT$(x, #n)` function which will retrieve x characters from the port opened as `#n`.

All serial communications are buffered, which means that MMBasic will copy any incoming characters to a part of memory (the buffer) where they can be retrieved later. The advantage of buffering is that instead of waiting for characters to arrive, your BASIC program can be doing something useful and just check from time to time to see if anything has arrived. The output is also buffered, so that when you send some characters they are sent in the background and your program can continue with something, else such as checking sensor inputs.

A typical use for the serial ports is interfacing with low-cost GPS modules. It only requires a few lines of BASIC to get your current speed, location and time from such a module with incredible accuracy. In the future we will present a number of projects using a Micromite and a GPS module that demonstrate how easy it is to do this.

### I$^2$C and SPI communications

Most sensors use either I$^2$C or SPI to communicate their results and the Micromite will work with either. Typical sensors include acceleration, compass, electronic gyroscopes, temperature, humidity, pressure, light intensity and dozens more.

Using the I$^2$C protocol is straightforward. First, open the I$^2$C channel using the `I2C OPEN` command. This allows you to specify the speed (up to 400kHz), address format (7 or 10 bits) and other details such as the timeout. With the port open you are the master and you can send data using the `I2C WRITE` command and receive the response using the `I2C READ` command.

The Micromite can also operate as a slave device. This means that you can program the Micromite chip to act as an intelligent slave to communicate results to another microcontroller. Acting as a slave also allows a Micromite to act as an expansion device for another Micromite – the *Micromite User Manual* provides an example of how to do this.

The SPI protocol is simpler than I$^2$C and is also used by many sensors. The Micromite can drive the SPI interface at up to 10MHz and has commands for sending and receiving bulk high-speed data as well as managing the transfer on a byte-by-byte basis.

### Interrupts

An interrupt is when the normal flow of the program is *interrupted* by some event. When this happens MMBasic will pause the main program and execute a special subroutine (the interrupt routine), which can be used to do something based on the interrupt. When this subroutine exits, MMBasic will recommence running the main program.

The important feature of an interrupt is that the main program is completely unaware that it has been paused and restarted again.

A typical use for an interrupt might be that your project has a push button which, when pressed, should turn on some device (eg, a light or motor). Meanwhile, the Micromite is doing some other task, for example, monitoring a number of voltage inputs.

To implement this in the conventional way you would need to continuously check the state of the input pin to determine if the button has been pressed. In a long program this would be tedious, as you would be forced to sprinkle statements throughout the main program such as:

```
IF PIN(nn) = 1 THEN …
```

With an interrupt it is much easier. First, you need to specify an interrupt, which will occur when the input pin goes high:

```
SETPIN nn, INTH, MySub
```

In this example, `nn` is the pin number, `INTH` specifies that the interrupt will occur when that pin goes high and `MySub` is the name of the subroutine that should be called when the interrupt occurs. We have not covered subroutines yet (next month) so for the moment, just think of a subroutine as a lump of code that can be executed.

The subroutine could look like this (xx is the number of an output pin that is driving the light or relay):

```
SUB MySub
  PIN(xx) = 1
EXIT SUB
```

So now, when the pushbutton is pressed, MMBasic will detect that the input has gone high, suspend the main program, and execute the code in the subroutine MySub. All this does is set an output pin high to turn on the light or relay. When MMBasic reaches the EXIT SUB command it will return to executing the main program.

Normally, an interrupt subroutine will have more than a single line in it but it does not have to be complicated – it just does its job then exits.

You can set an interrupt on any I/O pin and it can be triggered if the pin's input goes low, goes high or changes state (ie, goes either high or low). You can have up to ten I/O pins simultaneously operating as interrupts, each with its own interrupt subroutine.

Many other parts of MMBasic can also generate interrupts. For example, you can specify an interrupt that repeats with a specified number of milliseconds between each interrupt, you can have an interrupt when an IR remote control signal is received or when a certain number of bytes has been received on a serial interface.

### Timing

Keeping track of time is an important part of MMBasic and there are many ways that a program can access these features. The current date and time can be accessed using the special identifiers DATE$ and TIME$ which act like predefined variables. This internal clock is reset to zero on power up, but you can use the RTC command to set the correct time from an external real-time clock (RTC).

TIMER is another special identifier that returns the number of milliseconds since the Micromite has been powered up. You can use it to measure the time difference between two events or to wait a certain amount of time before doing something.

Another method of waiting for a defined time is the PAUSE command. Using this you can halt the execution of a program for a certain number of milliseconds. For example, after setting a control signal for a device you might be required to wait for a defined number of milliseconds before you can set the next control signal. The PAUSE command is perfect for this type of job.

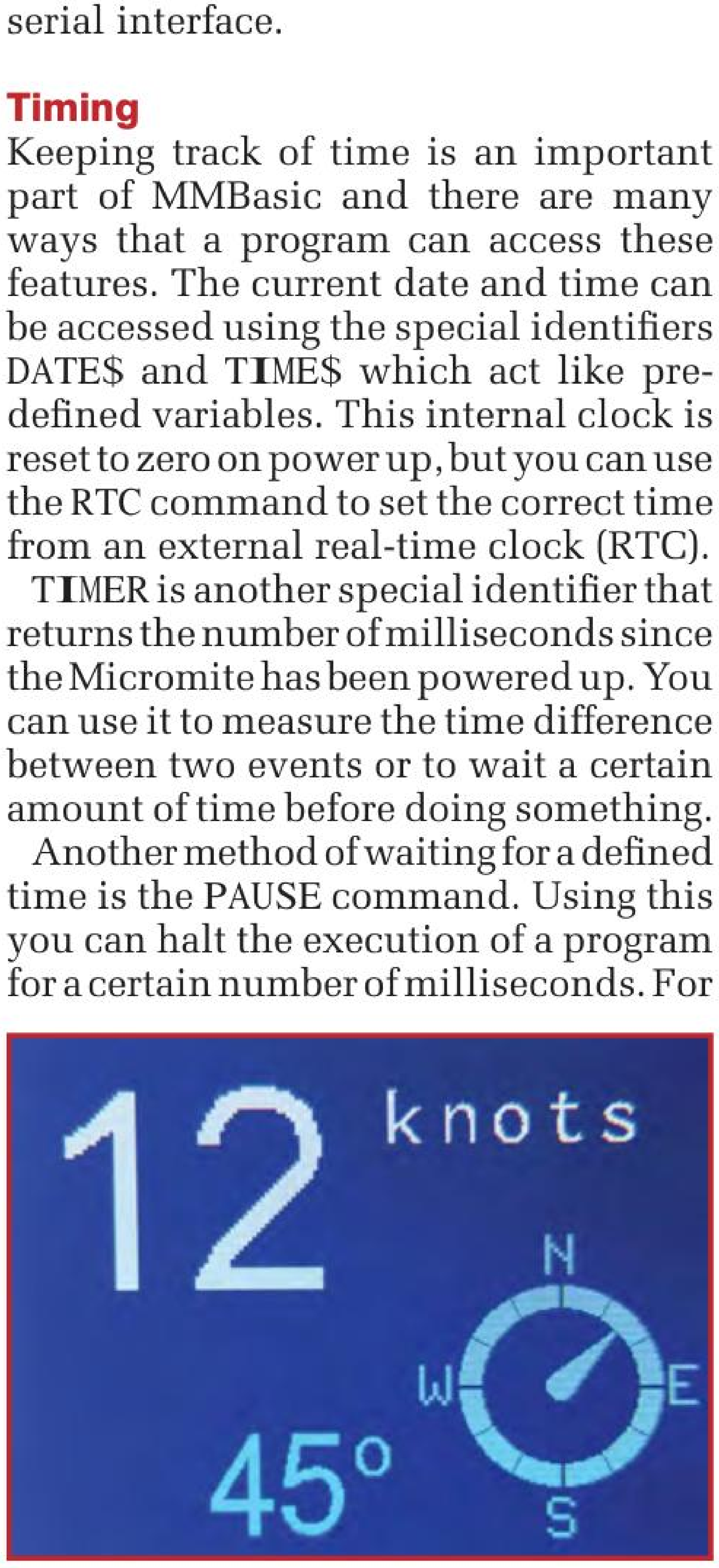


*Fig.4. Flexible and creative support for driving colour LCD displays*

MMBasic also allows you to set up to four 'tick' timers. Each acts like the tick of a clock and on each tick MMBasic will execute an interrupt subroutine specified in the command. The tick times are specified in milliseconds and can range from a few milliseconds to many days.

### Embedded controller features

With an embedded controller there is always the chance that something could go wrong. It could be that the program gets stuck in an endless loop or that the program contains an error, which forces MMBasic to exit to the command prompt. From the user's point of view the effect is the same, the chip has become unresponsive and only cycling the power will restart it.

The watchdog timer can guard against this type of event. This is a timer that counts down to zero and when it reaches zero the processor will be automatically restarted (the same as when power was first applied), even if MMBasic was sitting at the command prompt.

The WATCHDOG command should be placed in strategic locations in the program to keep resetting the timer and therefore preventing it from counting down to zero. Then, if a fault occurs, the timer will not be reset, it will reach zero and the program will be restarted (assuming the AUTORUN option is set).

Controlling the power consumption of the chip is another feature important in an embedded device, particularly if the device is to be battery powered. In the Micromite this can be done via the CPU command, which is used to control the processor's speed and therefore the Micromite's power consumption.

For example, CPU 5 will set the processor's clock speed to 5MHz with a power requirement of about 6mA and CPU 48 will set it to 48MHz which draws about 31mA. The BASIC program can change this at will, so it is possible to speed up the processor to execute a few lines of code and then revert back to a slow speed for the non-important portions of the program. Halving the clock speed roughly halves the power drain, so this is a useful technique.

The CPU SLEEP command will totally halt the processor's activity and reduce the Micromite's power drain to less than 100µA. During sleep, the program is in 'suspended animation' and MMBasic will monitor the wakeup pin (pin 16 on the 28-pin Micromite or pin 43 on the 44-pin chip) for a change of state (high to low, or vice versa). When this occurs, the Micromite will come out of sleep and resume running the program.

You can also tell a Micromite to sleep for a defined number of seconds. For example, CPU SLEEP 10 will cause the Micromite to sleep for ten seconds then automatically resume running the program.

The Micromite does not normally have a storage system (such as an SD card) attached, so the programmer needs a method of saving data such as calibration and configuration settings and then reloading them on power up. The VAR SAVE command will do this for you. It will save a list of specified variables in non-volatile Flash memory, which can later be reloaded on power up by using the VAR RESTORE command.

### Special devices

There are some devices that are often used in microcontroller projects and the Micromite provides special support for these. Using this built-in support you can easily add an infrared remote control or keypad input to your project with just a few lines of BASIC code. These special devices are:

- High-resolution, touch-sensitive multi-colour LCD display panel
- Infrared remote control receiver and transmitter
- The DS18B20 temperature sensor and DHT22 temperature/humidity sensor
- LCD display module
- Numeric keypad
- Battery-backed clock
- Ultrasonic distance sensor

### Colour touch-sensitive LCD display panel

As mentioned last month, the Micromite includes support for colour LCD display panels using the ILI9341 controller and an SPI interface –see Fig.4 and Fig.5. These have a 240 x 320 pixel colour TFT display, come in a variety of sizes (2.2-inch, 2.4-inch and 2.8-inch) and are low cost (typically £4). On eBay you can find suitable displays by searching for the controller name, 'ILI9341'. You can also use a loadable driver to add full support for LCD panels using other controllers (details are in the MMBasic firmware zip file).

In later articles we will cover the use of LCD panels in more detail, plus we will present a number of projects that use them to create a full-featured graphic and touch-sensitive interface for the user.

ILI9341-based displays use an SPI interface and most are supplied with a resistive touch-sensitive panel and associated controller chip, which is fully supported in MMBasic. To detect if and where the screen is touched you can use the following functions in a BASIC program:

| | |
|---|---|
| TOUCH(X) | Returns the X coordinate of the currently touched location |
| TOUCH(Y) | Returns the Y coordinate of the currently touched location. |

All coordinates and measurements on the screen are done in terms of pixels; the X coordinate indicates the horizontal position and Y the vertical position.

### Programming for the LCD panel

Colour is specified as a true-colour 24-bit number where the top eight bits represent the intensity of the red colour,

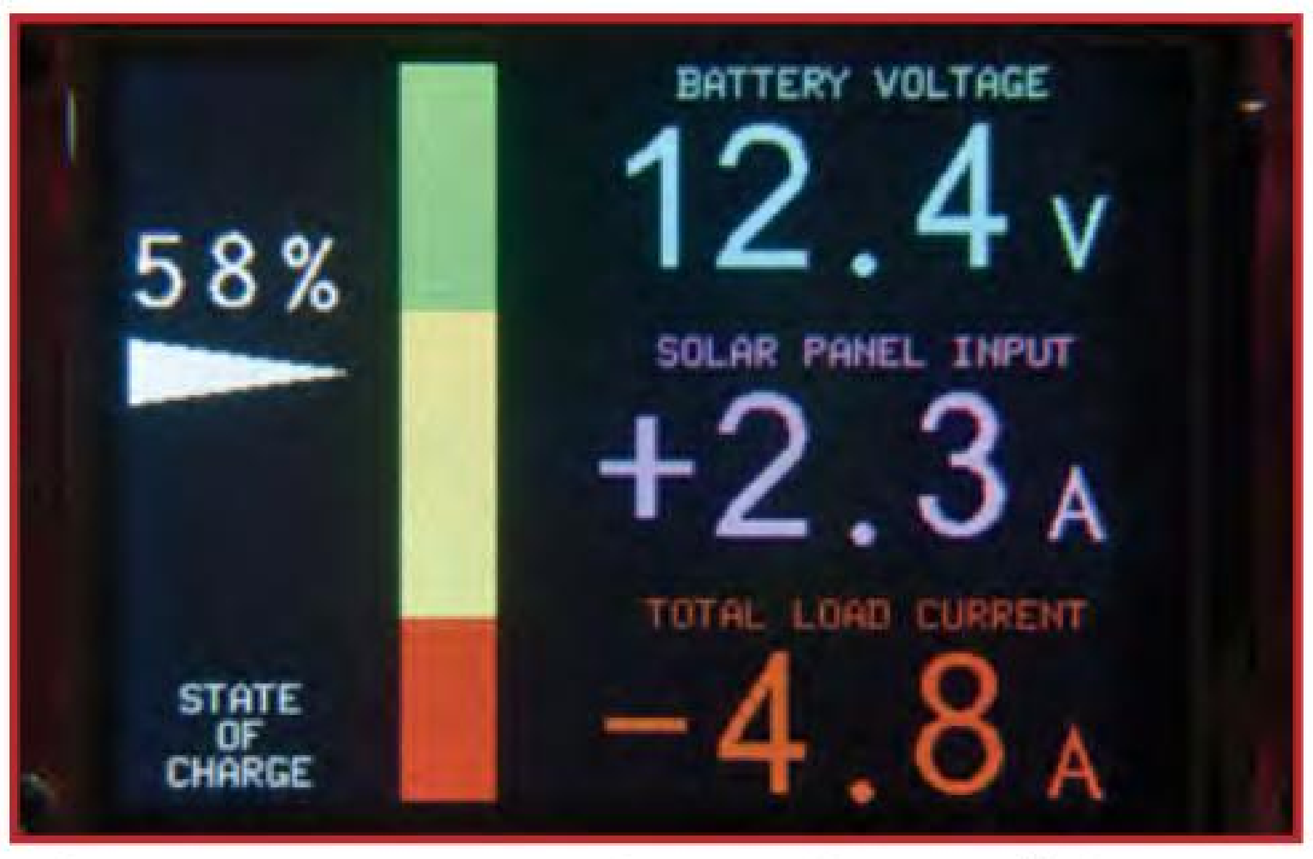


*Fig.5. Use your Micromite to drive a bespoke LCD-based meter*

the middle eight bits the green intensity and the bottom eight bits the blue. The easiest way to generate this number is with the RGB() function which has the form: `RGB(red, green, blue)`

A value of zero for a colour represents black and 255 represents full intensity. The RGB() function also supports a shortcut where you can specify common colours by naming them. The colours that can be named using the shortcut form are white, black, blue, green, cyan, red, magenta, yellow, brown and grey.

MMBasic includes one built-in font, which is 8 pixels wide by 13 pixels high and includes all 95 standard ASCII characters. If required, additional fonts can be embedded in a BASIC program. The MMBasic firmware zip file includes over a dozen embedded fonts covering a wide range of character sets.

There are eight basic drawing commands that you can use within MMBasic programs on the Micromite to interact with an attached LCD display. In the following commands, C is the drawing colour and defaults to the current foreground colour. FILL is the fill colour that defaults to –1, which indicates that no fill is to be used. The drawing commands are:

`CLS C`
Clears the screen to the colour C.

`PIXEL X, Y, C`
Illuminates a pixel.

`LINE X1, Y1, X2, Y2, LW, C`
Draws a line starting at X1 and Y1 and ending at X2 and Y2. LW is the line's width.

`BOX X1, Y1, W, H, LW, C, FILL`
Draws a box starting at X1 and Y1, which is W pixels wide and H pixels high. LW is the width of the sides of the box.

`RBOX X1, Y1, W, H, R, C, FILL`
Draws a box with rounded corners starting at X1 and Y1 which is W pixels wide and H pixels high. R is the radius of the corners of the box.

`CIRCLE X, Y, R, LW, A, C, FILL`
Draws a circle with X and Y as the centre and a radius R. LW is the width of the line used for the circumference, A is the aspect ratio.

`TEXT X, Y, STRING, JUSTIFICATION, FONT, SCALE, C, BC`
Displays a string starting at X and Y. JUSTIFICATION is one or two letters where the first letter is the horizontal justification around X and can be L, C or R for LEFT, CENTER, RIGHT and the second letter is the vertical placement around Y and can be T, M or B for TOP, MIDDLE, BOTTOM.

FONT and SCALE specify the font and scale. C is the drawing colour and BC is the background colour.

`GUI BITMAP X, Y, BITS, WIDTH, HEIGHT, SCALE, C, BC`
Displays the bits in a bitmap starting at X and Y. HEIGHT and WIDTH are the dimensions of the bitmap, SCALE, C and BC are the same as for the TEXT command.

## Infrared remote control send/receive

To add a remote control to your project you can use the IR command. When enabled, this function will run in the background and interrupt the running program whenever a key is pressed on the IR remote control.

This function will work with any NEC or Sony-compatible remote control, including ones that generate extended messages. Most cheap programmable remote controls will generate either protocol, and using one of these you can add a sophisticated flair to your Micromite-based project. Other manufacturers, including Apple, Pioneer, Sanyo, Akai and Toshiba also use the NEC protocol, so their name brand remotes can be used.

To detect the IR signal you need an IR receiver connected to the IR pin (pin 16 on a 28-pin chip) as illustrated in Fig.6. The IR receiver will sense the IR light, demodulate the signal and present it as a TTL-voltage-level signal to this pin. Setup of the I/O pin is automatically done by the IR command.

When an infrared signal is received, MMBasic will update a variable with the received device code and a second variable with the function code. MMBasic will also interrupt your program and run a specified subroutine where you can take some action based on the command received. All this takes place in the background so your main BASIC program can continue with its main function without having to wait for the signal.

IR remote controls can address many different devices (eg, VCR, TV) so the program would normally examine the device code first to determine if the signal was intended for the program and, if it was, then take action based on the key pressed.

The IR function uses the same I/O pin as the wakeup signal for the CPU SLEEP command, and it is possible to combine them so that an incoming IR signal will wake the Micromite, which will then decode the IR signal. In this way you can have a Micromite running on battery power that will wake up on an IR signal, do something based on the signal, then go back to sleep.

Using the IR SEND command you can transmit a 12-bit Sony infrared remote control signal using an infrared LED. Fig.7 shows a suitable circuit. This is primarily intended for Micromite-to-Micromite communications, but it can also be used to control Sony equipment that uses 12-bit codes.

## Measuring temperature

The TEMPR() function will get the temperature from a DS18B20 temperature sensor – see Fig.8. This device can be purchased on eBay for about £3 in a variety of packages, including a waterproof probe version.

The connection of the DS18B20 to the Micromite is simple (see Fig.9) and to get the current temperature you just use the TEMPR() function in an expression. For example:

```
PRINT "Temperature: " TEMPR(pin)
```

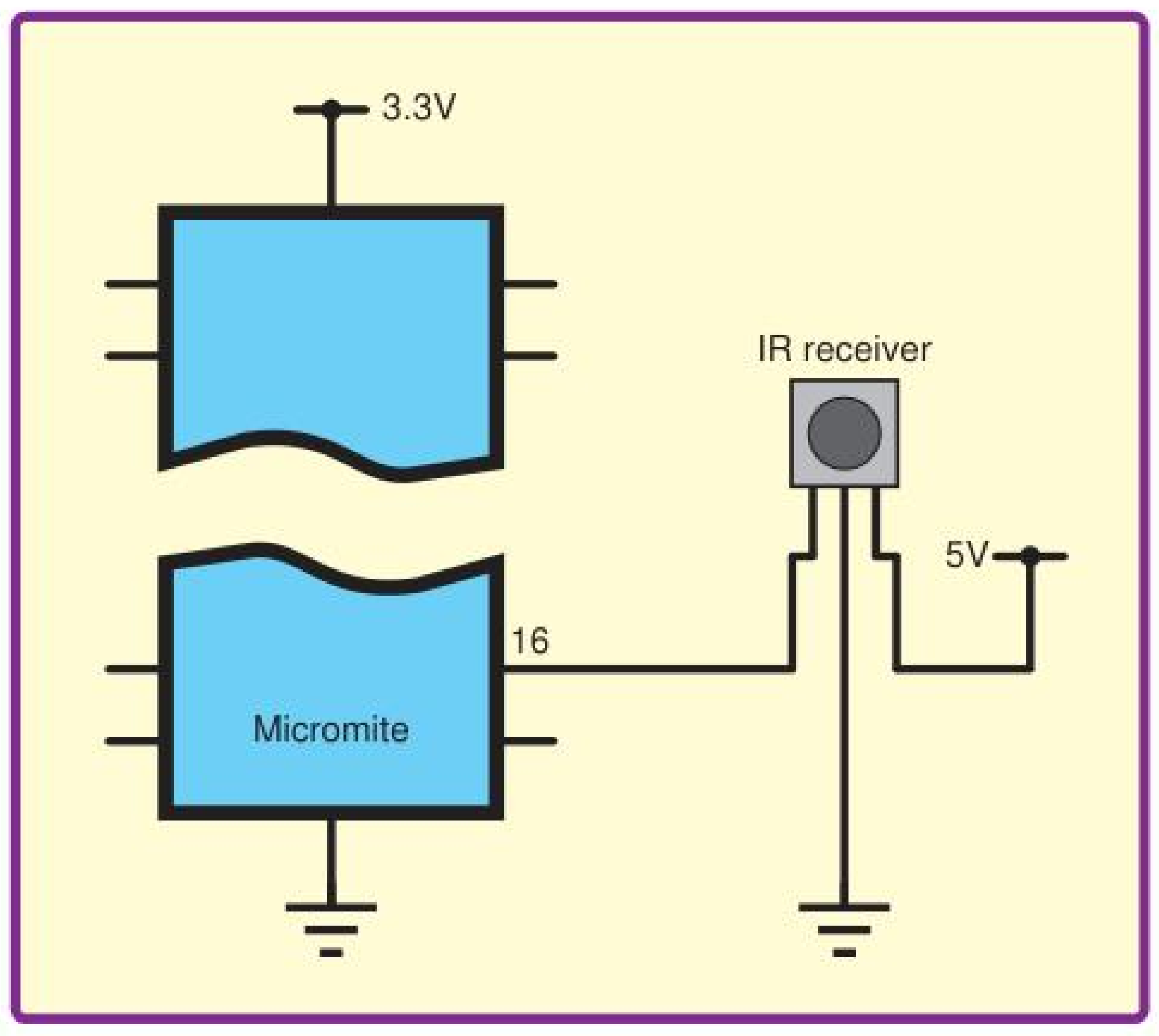


*Fig.6. Interfacing the Micromite to an infrared receiver*

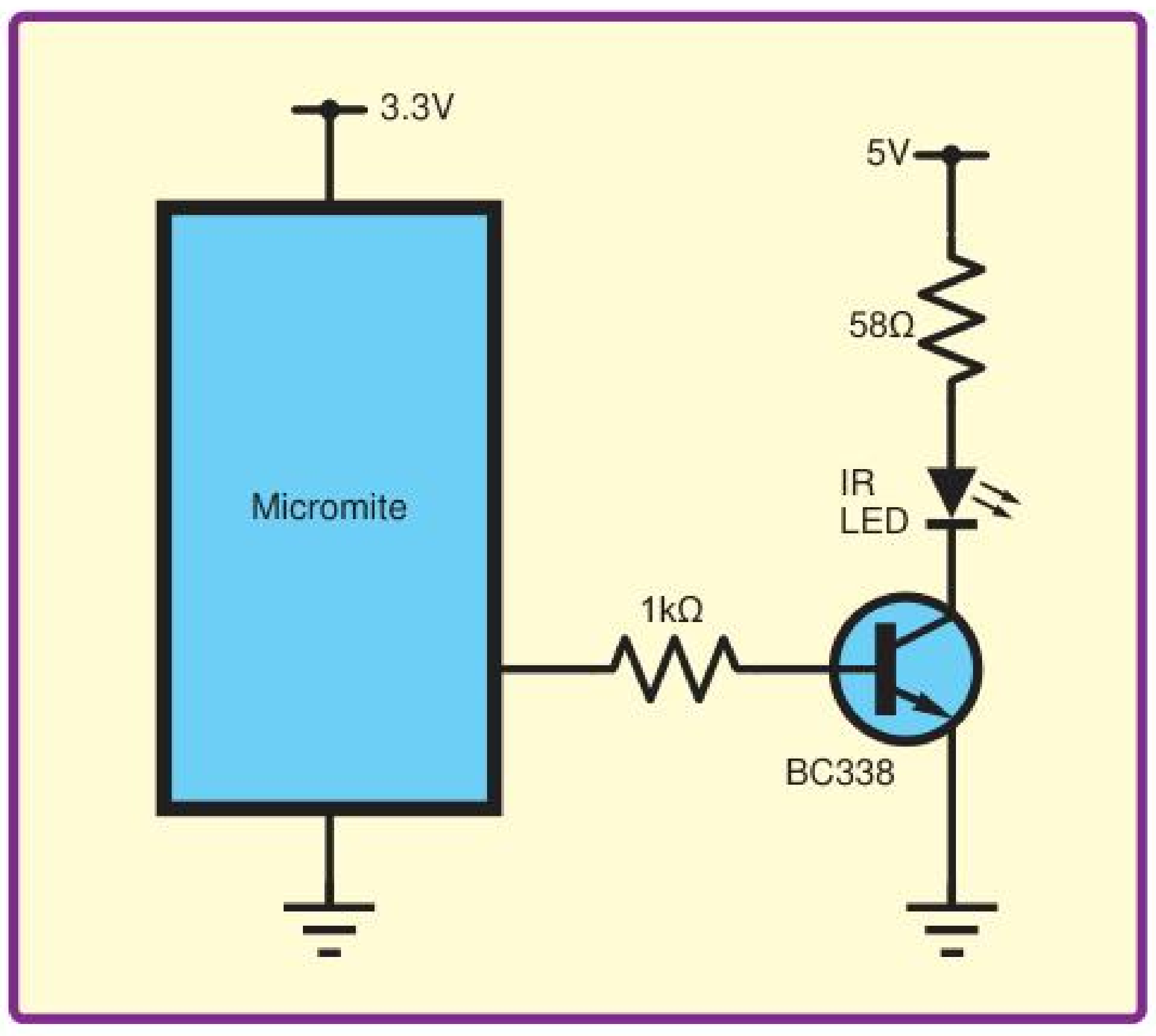


*Fig.7. Interfacing the Micromite to an infrared LED*

*Fig.8. Easy temperature measurement with the DS18B20 sensor*

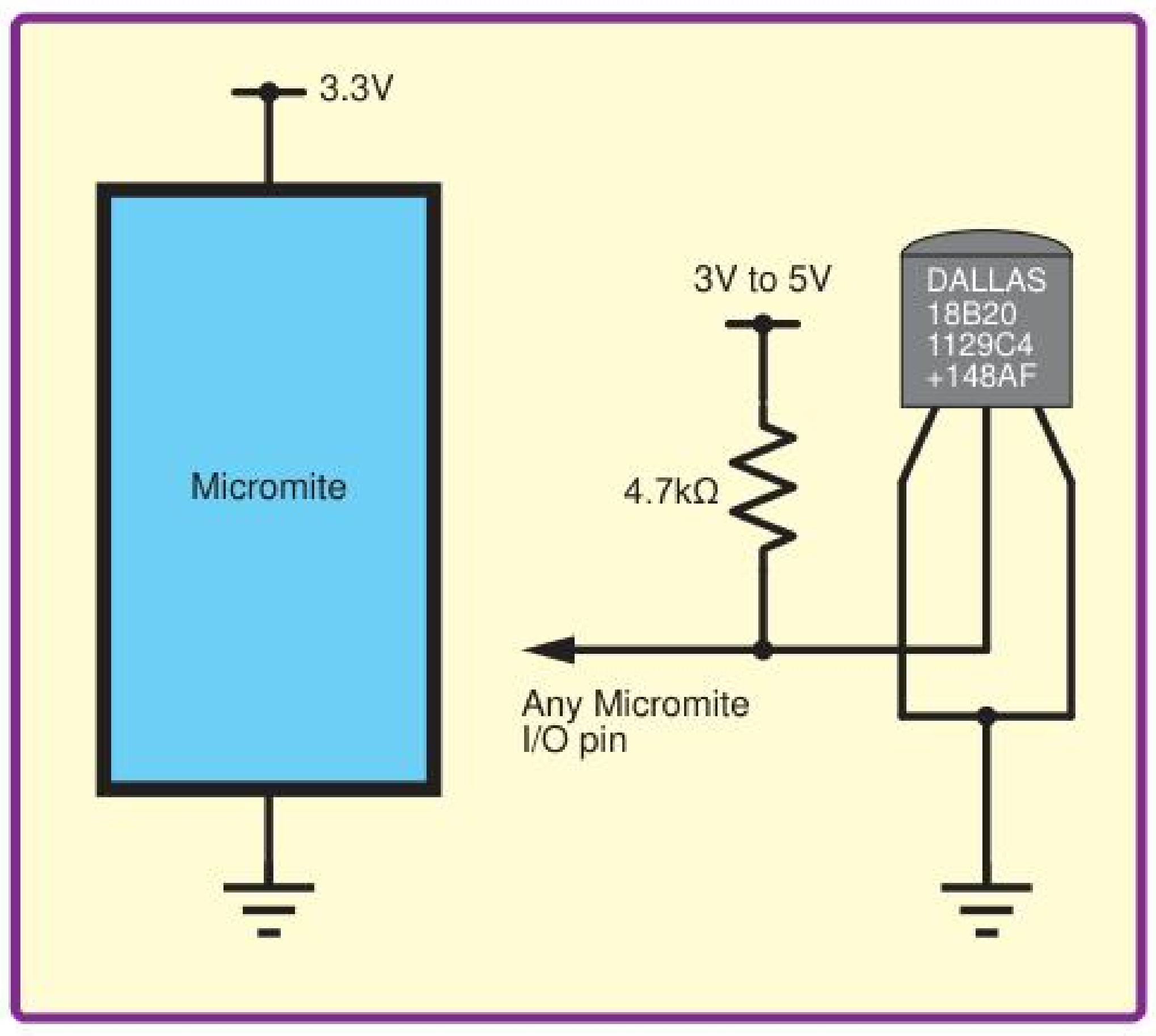


*Fig.9. Interfacing the Micromite to a DS18B20 temperature sensor*

Where 'pin' is the I/O pin to which the sensor is connected. You do not have to configure the I/O pin – that is handled by MMBasic.

The returned value is in degrees Celsius with a resolution of 0.25°C and is accurate to ±0.5°C. If there is an error during the measurement the returned value will be 1000.

The time required for the overall measurement is 200ms and the running program will halt for this period. If you do not want this you can separately trigger the conversion using the TEMPR START command, then later use the TEMPR() function to retrieve the temperature reading without halting the main program.

## Measuring humidity

The HUMID command will read the humidity and temperature from a DHT22 humidity/temperature sensor. This device is also sold as the RHT03 or AM2302, but all are compatible and can be purchased on eBay for under £3.

The DHT22 can be powered from 3.3V or 5V (5V is recommended) and it should have a pull-up resistor on the data line. This is suitable for long cable runs (up to 20m) but for short runs the resistor can be omitted because the Micromite also provides an internal weak pull-up.

To get the temperature or humidity you use the HUMID command with three arguments, which are the I/O pin to use, a floating point variable in which the temperature is returned and another variable for the humidity.

The temperature is returned as degrees Celsius with a resolution of one decimal place (eg, 23.4) and the humidity is returned as a percentage relative humidity (eg, 54.3). If there is an error (eg, the sensor is not connected or communicating correctly) the command will return 1000 for both the temperature and humidity.

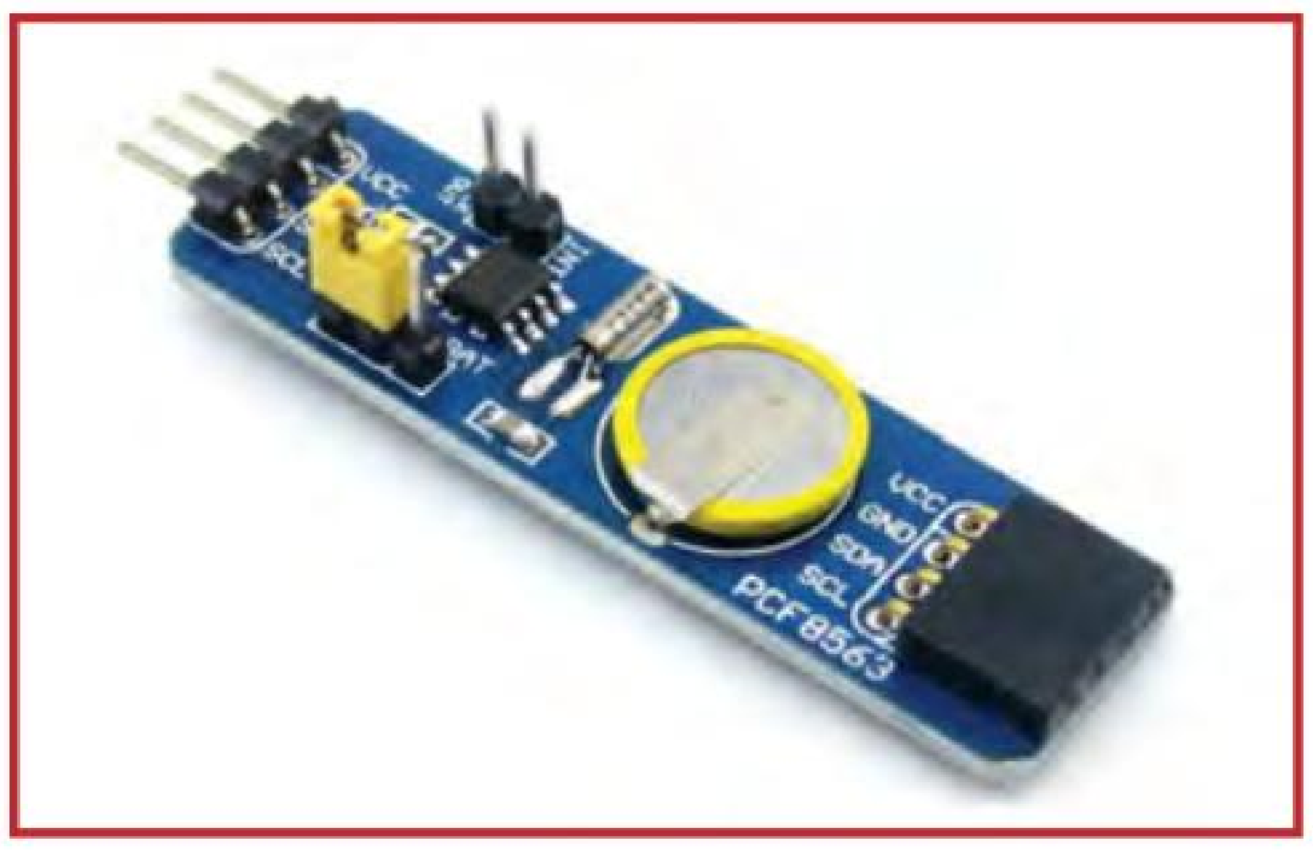


*Fig.10. Real-time clock module*

## Real-time clock interface

Using the RTC GETTIME command it is easy to get the current time from a PCF8563, DS1307, DS3231 or DS3232 real-time clock (RTC) as well as compatible devices such as the M41T11. These integrated circuits are popular and cheap, will keep accurate time with the power removed and can be purchased for a few pounds on eBay. Complete modules, including the battery can also be found for a little more.

The PCF8563 (see Fig.10) and DS1307 will keep time to within a minute or two over a month, while the DS3231 and DS3232 are particularly precise and will remain accurate to within a minute over a year.

These chips are I$^2$C devices and should be connected to the I$^2$C I/O pins of the Micromite. Fig.11 shows a typical circuit for the PCF8563. The other chips have similar circuits (check their data sheets).

Before you can use the RTC its time must be set. That is done with the RTC SETTIME command, which takes six arguments specifying the year, month, day, hour, minute, and second.

To get the time you use the RTC GETTIME command, which will read the time from the real-time clock chip and set the clock inside the Micromite. Normally, this command will be placed at the beginning of the program or in the subroutine MM.STARTUP so that the time is set on power up.

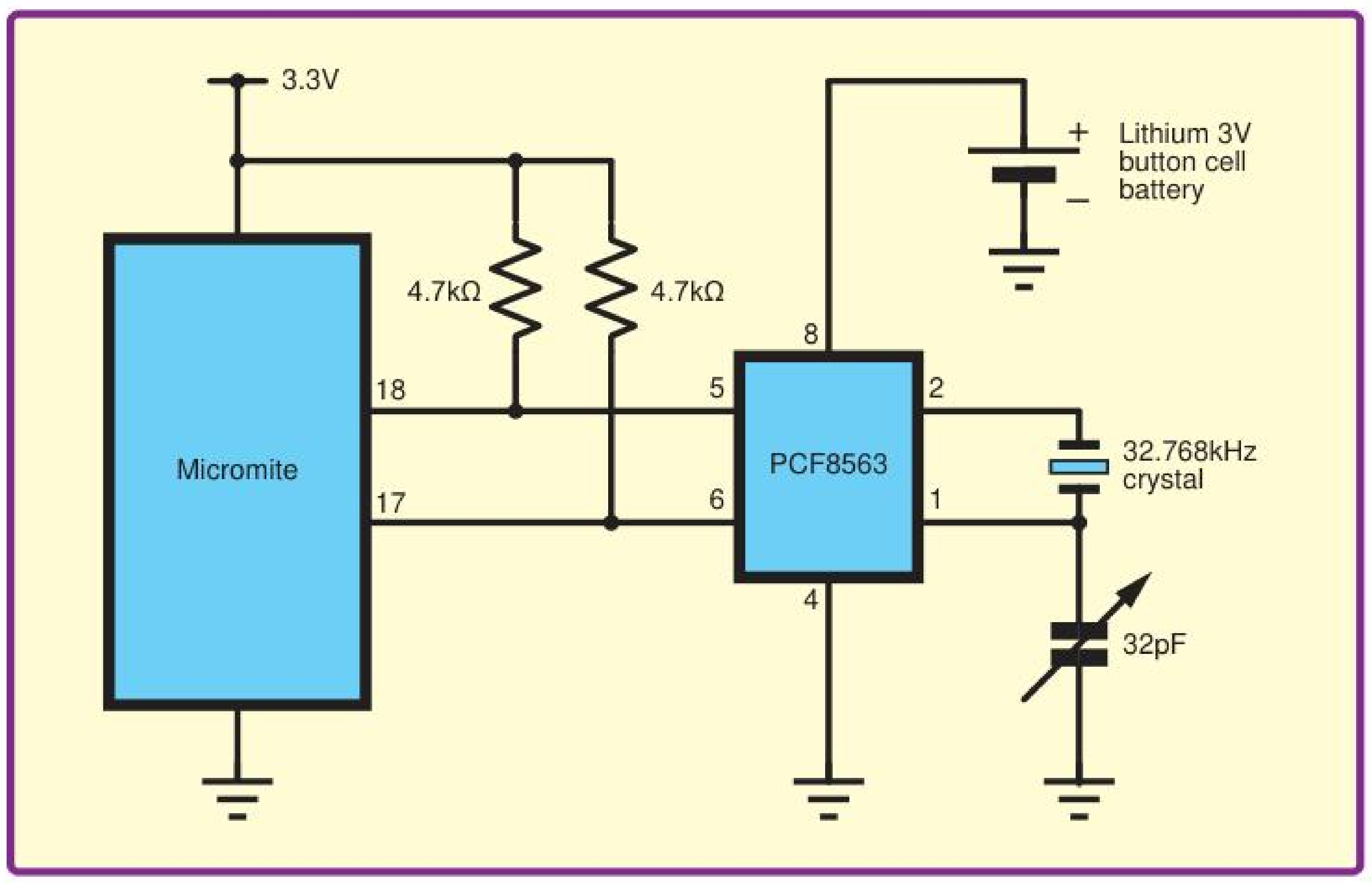


*Fig.11. Interfacing the Micromite to a real-time clock*

## Measuring distance

Using an HC-SR04 ultrasonic sensor and the DISTANCE() function you can measure the distance to a target.

This low-cost device can be found on eBay and it will measure the distance to a target from 3cm to 3m. It works by sending an ultrasonic sound pulse and measuring the time it takes for the echo to be returned. Compatible sensors are the SRF05, SRF06, Parallax PING and the DYPME007 (which is waterproof and therefore good for monitoring the level of a water tank).

On the Micromite you use the DISTANCE function that specifies the two I/O pins used by the sensor. You can also use three-pin devices and in that case only one pin number is specified. The value returned will be the distance in centimetres to the target or –1 if no target was detected. If you repeatedly call this function you must arrange for a delay of at least 60ms between each call, otherwise errors may occur (caused by an echo from the previous sound pulse).

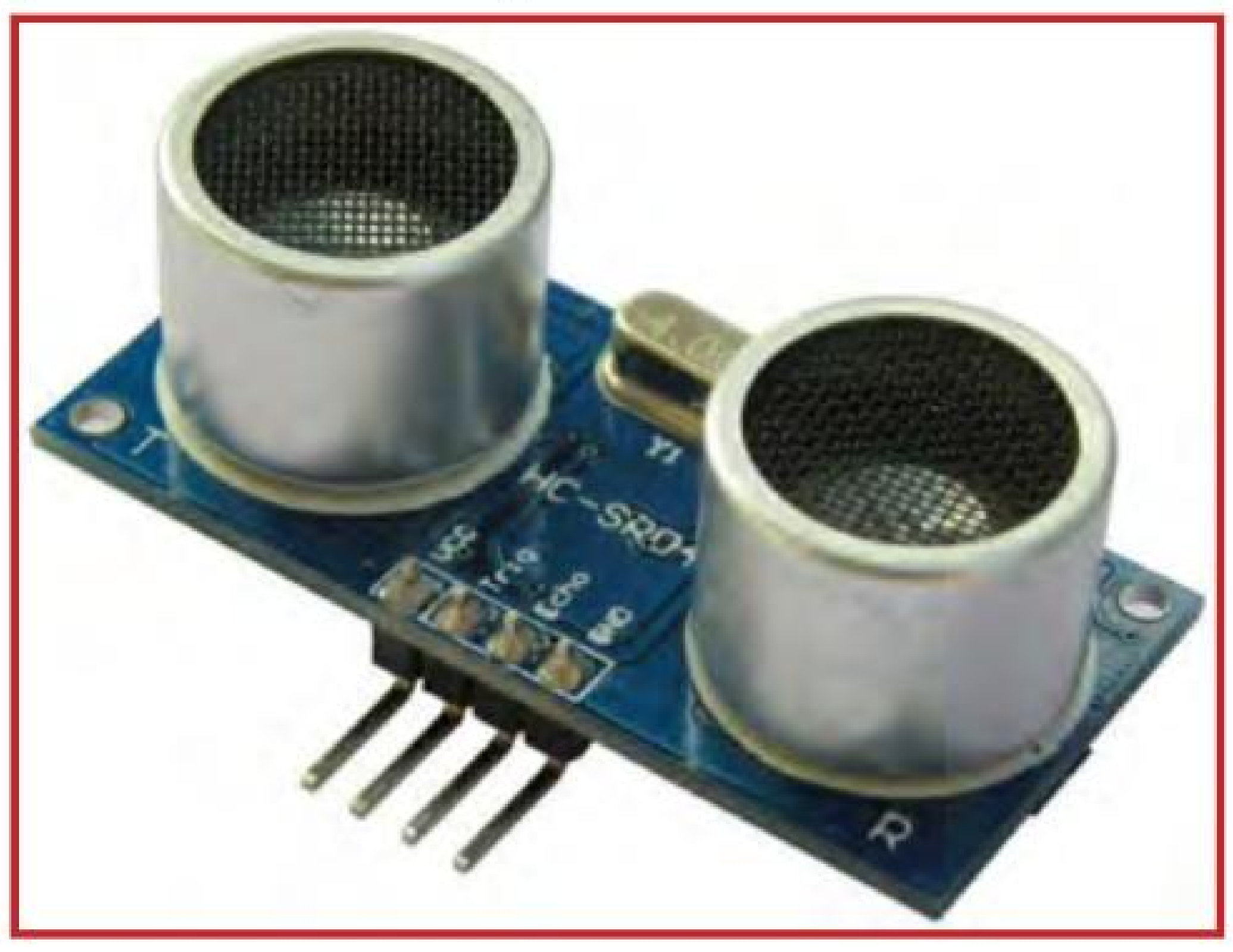


*Fig.12. HC-SR04 ultrasonic sensor*

## LCD modules

The LCD command will display text on a standard two or four-line monochrome LCD module with the minimum of programming effort. This command will work with LCD modules that use the KS0066, HD44780 or SPLC780 controller chip and a typical display is the LCD16X2 from **futurlec.com**

To set up the display you use the LCD INIT command, which specifies the I/O pins connected to the display (see Fig.13). Any I/O pins on the Micromite can be used and you do not have to set them up beforehand (the LCD command automatically does that for you).

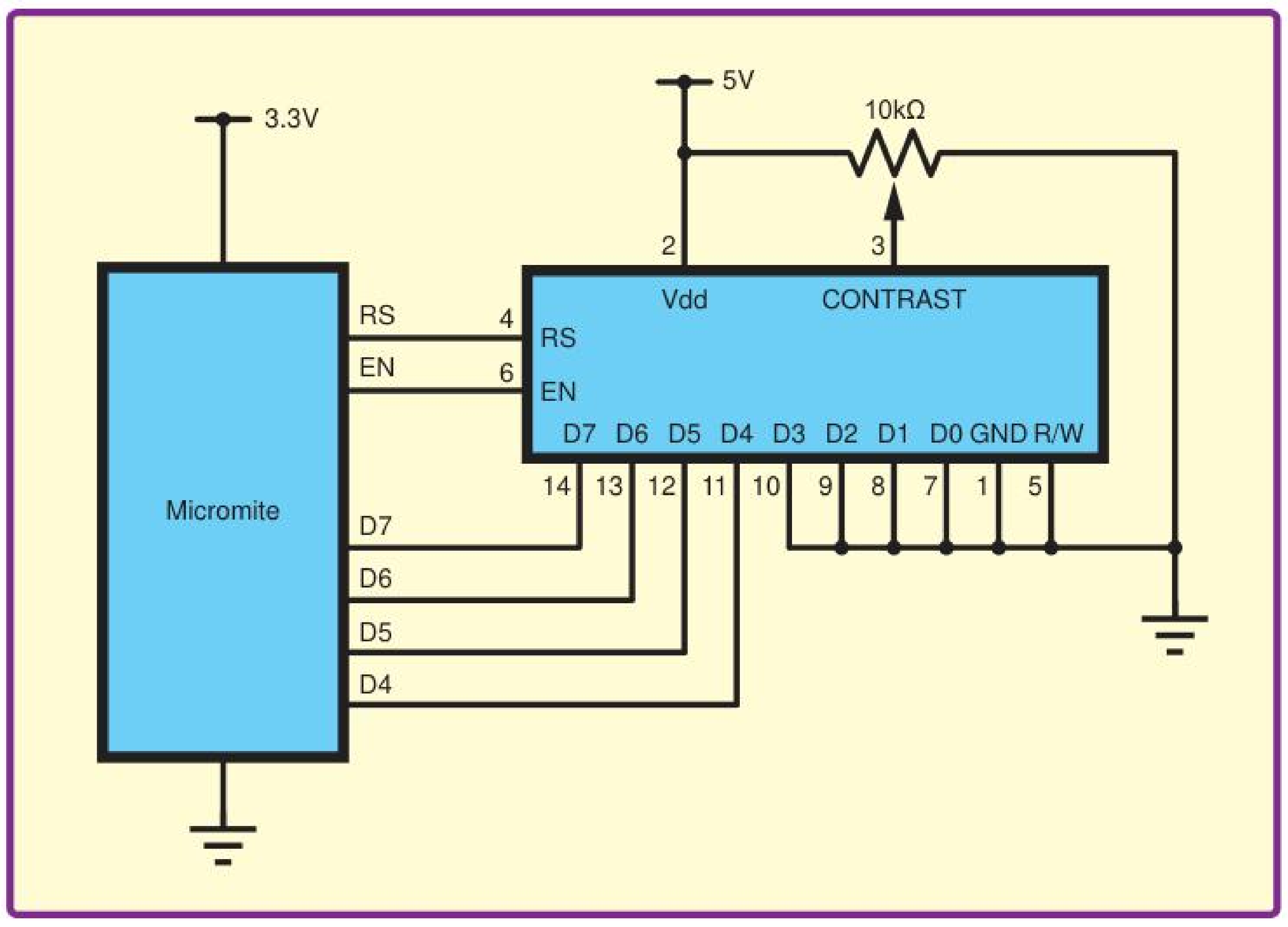


*Fig.13. Interfacing the Micromite to an LCD*

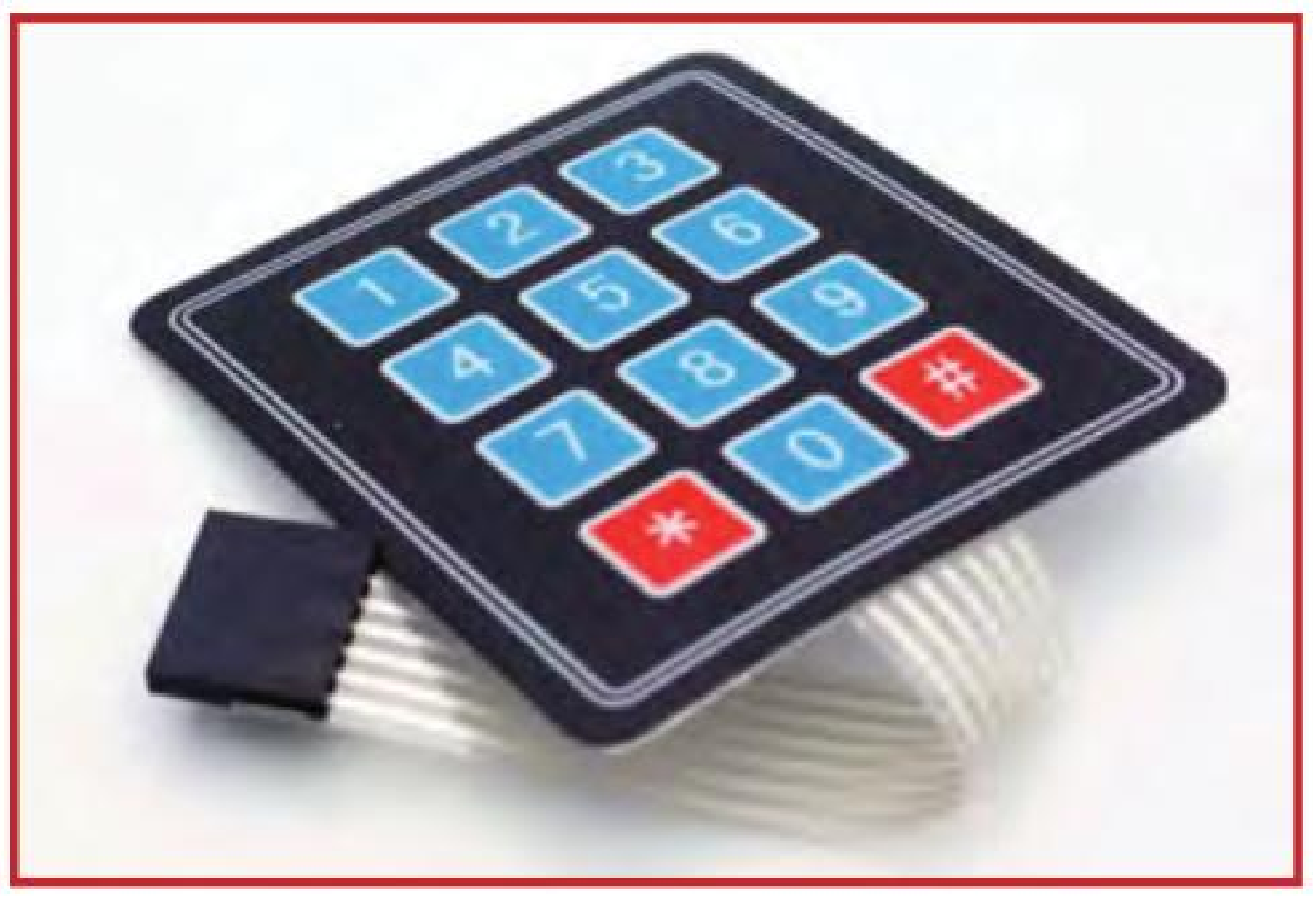


Fig.14. 4 × 3 keypad suitable for Micromite interfacing

To display characters on the module you use the LCD command that specifies the line to update, the position in the line and finally the characters to display.

### Keypad interface

A keypad is a simple method of entering data into a Micromite-based system. The Micromite supports either a 4 × 3 keypad (Fig.14) or a 4 × 4 keypad, and the monitoring and decoding of key presses is done in the background. When a key press is detected an interrupt will be issued that allows the BASIC program to deal with it.

To enable the keypad feature you use the KEYPAD command that specifies the variable to update with the keypad value, the subroutine to be called when a button is pressed and the 7 or 8 I/O pins that are used to interface to the keypad.

The detection and decoding of key presses is done in the background and the program will continue after this command without interruption. When a key press is detected the value of the variable will be set to the number representing the key and an interrupt triggered so that your program can immediately respond.

### Switches and rotary encoders

Often, there is a need to use a switch as an input to a Micromite-based project. This is easy to implement as a Micromite input can be specified with a pull-up resistor. This resistor is about 100kΩ and is internal to the Micromite and (when specified) will be connect between the input pin and the 3.3V supply. This means that the switch can be connected between the ground and the input pin. When the switch is open the input will be high (pulled up by the internal resistor) and when closed the input will be zero.

When you use a switch you will also have to consider the issue of contact bounce. This is when the switch contacts mechanically touch and then bounce apart momentarily due to the momentum of the mechanical assembly. Because the Micromite runs very fast, a BASIC program could see this as a succession of quick button presses rather than a single press.

You could check for this in your program, for example by checking 100ms after the first contact closure to confirm that the contacts are indeed closed. A simpler solution is to connect a 100nF capacitor across the switch contacts. This capacitor, in association with the internal pull-up resistor will average out any rapid contact bounce so that the program will see a smooth transition from on to off, and vice versa.

A rotary encoder is a handy method of adjusting the value of parameters in a microcontroller project. A typical encoder can be mounted on a panel with a knob and looks like a potentiometer. As the knob is turned switches within the encoder generate a series of signals known as a 'Gray Code'. A simple program (included in the *Micromite User Manual*) can be used to decode this code.

### Next month

That is all that we have room for this month. Next month, we will introduce you to the fine art of programming in the BASIC programming language.

## Keep up to date!

For updates to the Micromite firmware you can visit the author's website at: **http://geoffg.net/micromite.html**.

Another resource is The Back Shed forum where there are many Micromite users who are happy to help newcomers, see: **www.thebackshed.com/forum/Microcontrollers**

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# NET WORK

by Alan Winstanley

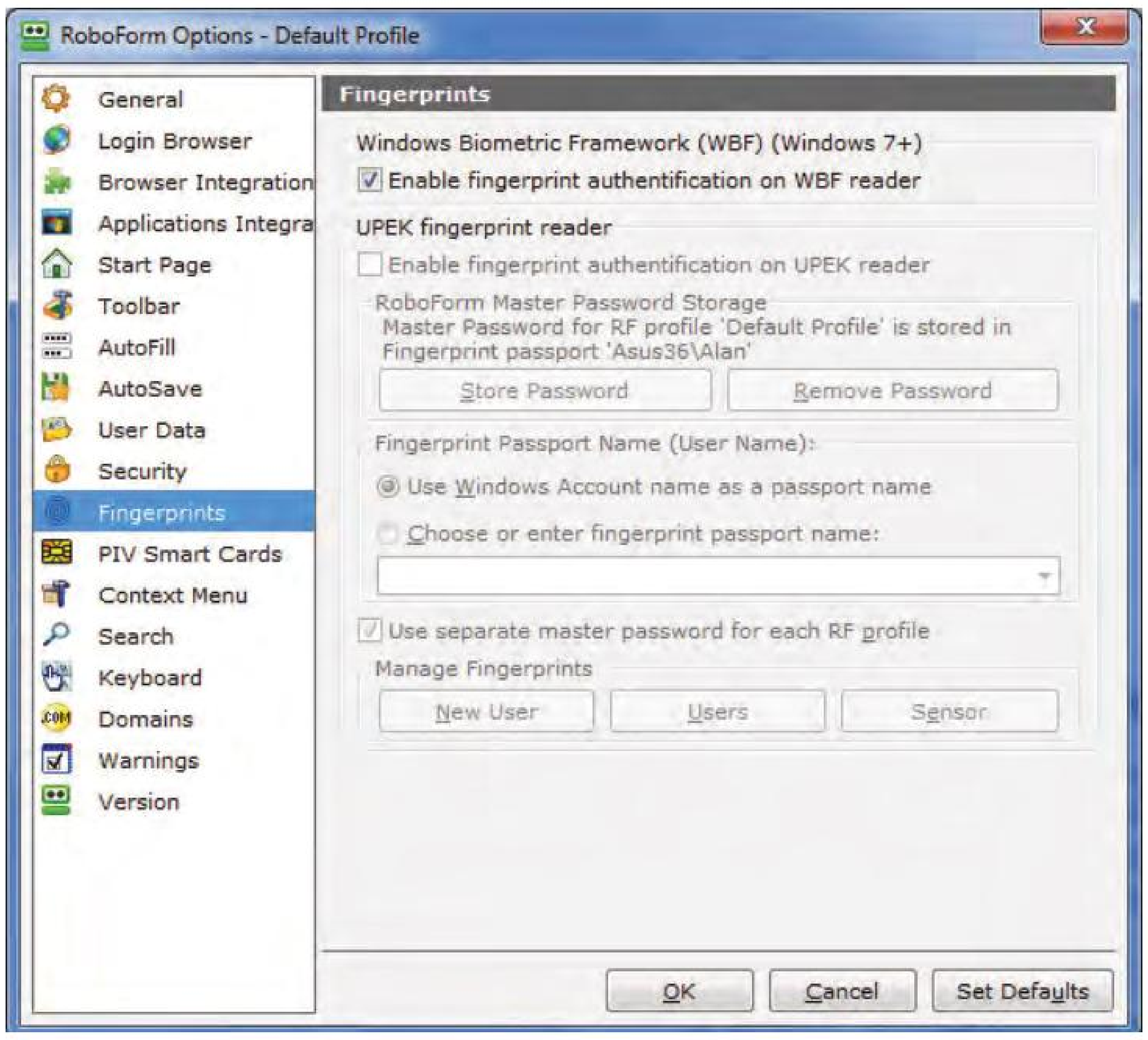
## Traditional values

LIKE MANY power users, I have a software toolbox containing several programmes that I find indispensable in helping me cope with my busy life online. Some readers may be surprised that I still happily manage all my email using Eudora, a much-loved programme abandoned by Qualcomm more than a decade ago, but still enjoying a good fan base today. Handling email offline suits me fine and Eudora's speed, power, flexibility and occasional humorous jibes more than compensate for its few little oddities. From experience, Eudora's biggest drawbacks are its failure to forward HTML mail properly – I simply print them to a PDF instead – and although Eudora will display a screen font such as Verdana, my recipients often only see Times New Roman; no-one ever complained that my emails were illegible as a result, though.

Eudora works well with POP3 and IMAP, and can be coaxed into working with Gmail. Doubtless a legacy offline email client like Eudora will not suit the latest wave of Internet users, but more traditional power users with some PC skills might want to take a look. I have it running on Windows XP, 7 and 8 and version 7.1.0.9 – the last and best – can be downloaded from: **FileHippo.com**

An old-school Eudora mailing list is still alive at **http://listmoms.net/eudora-win/index.html** which contains some key tips, although I found it rather unfriendly in nature. There is plenty of life in Eudora yet, and as a personal project I hope to put some Eudora resources online in the future.

Hand in hand with Eudora goes Firetrust's Mailwasher Free, a popular filtering program that screens out spam prior to downloading mail. Users can also bounce mail back as undeliverable (use with care). The free version of Mailwasher is limited to one POP3 email account, has no Recycle bin, and a limited preview pane. More details from: **www.firetrust.com/freebies**



Fingerprints

Windows Biometric Framework (WBF) (Windows 7+)

☑ Enable fingerprint authentification on WBF reader

UPEK fingerprint reader

☐ Enable fingerprint authentification on UPEK reader

RoboForm Master Password Storage

Master Password for RF profile 'Default Profile' is stored in Fingerprint passport 'Asus36\Alan'

Fingerprint Passport Name (User Name):

● Use Windows Account name as a passport name

○ Choose or enter fingerprint passport name:

☑ Use separate master password for each RF profile

Manage Fingerprints

*Roboform includes an option to use biometric security for secure logins*

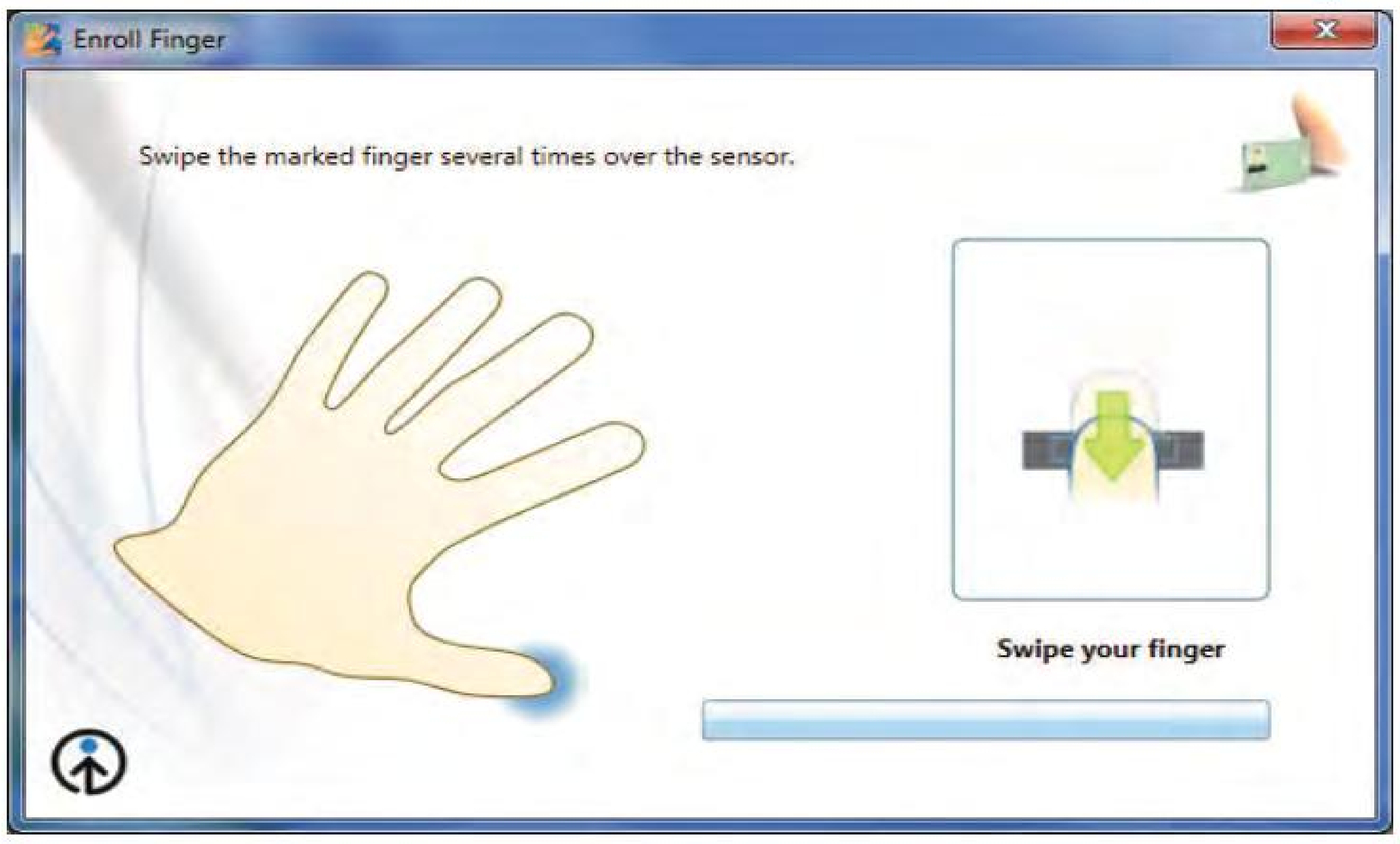
Probably the most productive programme that I use is Siber Systems' Roboform (**www.roboform.com**) which enables rapid log-ins into websites (hundreds, in my case) using a username and password combination (collectively a 'login'). This indispensable utility greatly speeds access to any website that demands a login, and it embeds a handy toolbar into popular web browsers, automatically sensing the website URL and prompting you to log into it with a single mouse click. Logins are AES 256 encrypted on disk and a portable version can be hosted on a USB key such as a robust Kingston Data Traveler Locker (*Net Work*, February 2015).

Roboform is also great for remembering details of mundane fill-in forms, so that if you have to regularly complete a tech support form (say) with the same old information, Roboform can automatically populate those fields for you in the future. A useful tip is to use Roboform to store the contents of a lengthy form just in case (for example) you forgot to log in somewhere, or the web page crashes. Some web forms habitually lose all your details if you wander off elsewhere, so when you return to the fill-in form you find everything has been erased – Roboform can fill them all in again for you with a single mouse click. Other software features include a password generator and 'Safenotes' – a scratchpad area to write notes next to logins.

### Helping hands

Following hard on the heels of our November issue and the fingerprint access controller project, one function that caught my eye in Roboform was the option of fingerprint scanning. Cost is a problem, as some USB fingerprint readers are quite expensive, typically £60 or more, but I managed to obtain a brand new legacy Dell FP-61001 USB fingerprint scanner on eBay for about £9. It was supplied with two USB leads (short and long) but no software or drivers, but the vendor claimed it was compatible with Windows 7 through 10. At that price it was worth a try!

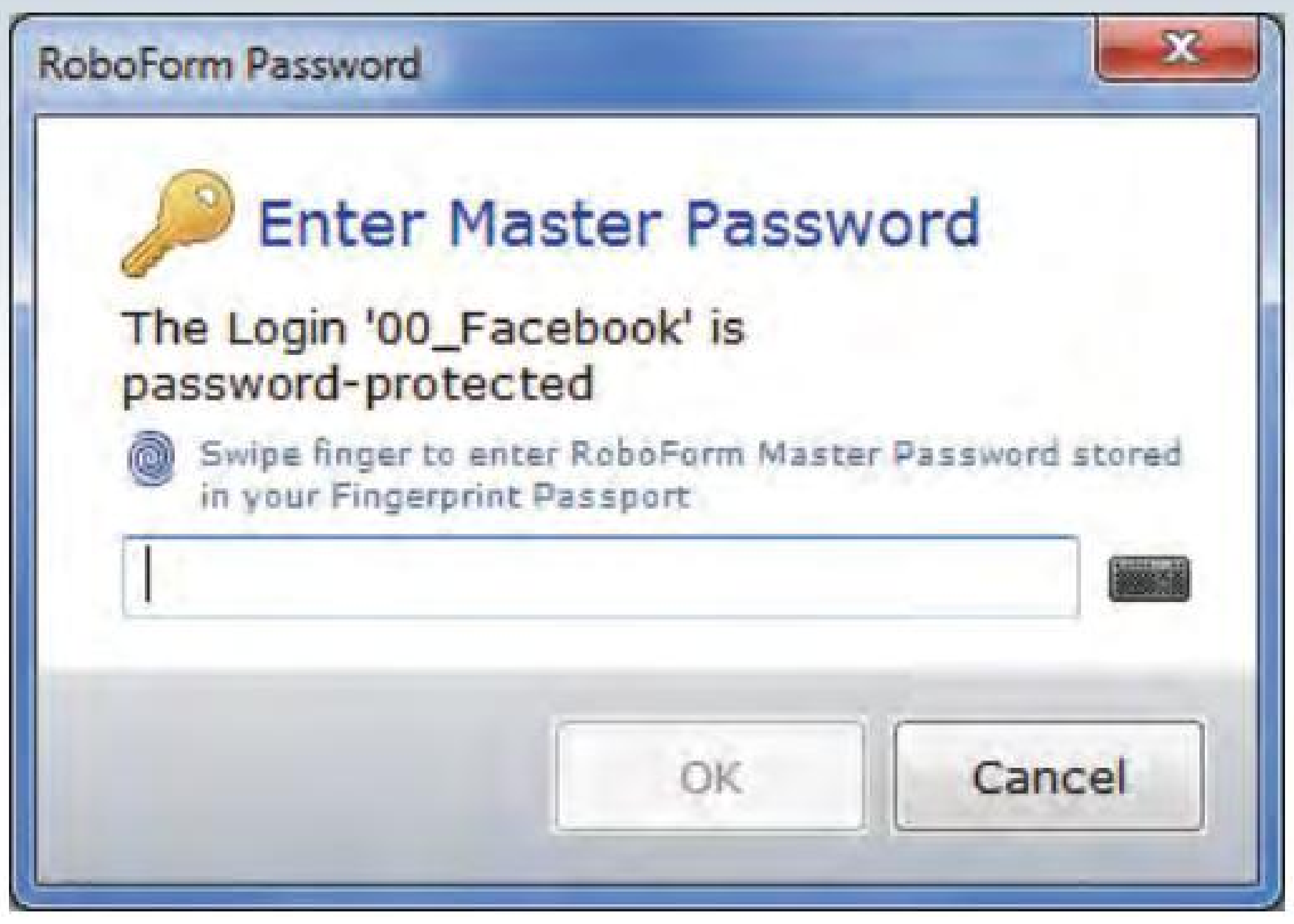
I stumbled upon two issues to address: installing the hardware and then the Windows software for capturing (or enrolling) fingerprints. The hardware side was a simple matter for Plug 'n Play and I soon saw Biometric Devices appear in the Windows control panel. That was a false dawn, though, as the hyperlinks shown merely tried to reach the Authentec website which was defunct. It turned out that Authentec had merged



Swipe the marked finger several times over the sensor.

Swipe your finger

*Scanning fingerprints to 'enrol' them – it works well enough*



RoboForm Password

Enter Master Password

The Login '00_Facebook' is password-protected

Swipe finger to enter RoboForm Master Password stored in your Fingerprint Passport

*Roboform then helps you log into websites using your fingerprint, or enter the master password*

*Using the Dell FP-61001 fingerprint scanner to log into websites*

with fingerprint sensor maker UPEK in the past. (This alliance was in turn snapped up by Apple when they were keen to add fingerprint sensing to their products.) The mention of UPEK was significant because Roboform offers a tantalising optional tick-box to 'enable UPEK fingerprint reader', but in my case it was permanently greyed out for some reason.

With the scanner plugged in, the question of Windows software proved far messier to resolve. Both the Authentec and UPEK websites were long gone, necessitating an online hunt to find suitable drivers. Guided by some handy forum posts I worked out that this Dell scanner was a 'TC' fingerprint reader with TCD21/TCD4x, and so the UPEK Windows 64-bit software was downloaded from Dell's website. In my case, the all-important file was **upek_windows-biometric--fram_a00_r308124.exe**, which after running an installer produced the UPEK Windows Biometric Framework driver clearly designed for various Dell computers. However, it ran on my Asus homebrew Windows 7 64-bit PC without a hitch. See: **http://tinyurl.com/z7qa6kg** for URLs and information, as I found no front-end links pointing to the drivers on Dell's website.

Installation simply created a folder containing that all-important **enroll.exe**, to which I added a desktop shortcut. This opened a scanning window (at last!) where my fingers and thumbprints could now be scanned. In Roboform, the option to 'Enable fingerprint authentication in WBF' (Windows Biometric Framework) was duly checked; the UPEK option remained disabled though. After scanning my 'dabs' on the Dell fingerprint reader I was in business.

Adding the USB scanner also created the option to log into Windows using a fingerprint, but for website access Roboform requires you to 'protect' logins (right-click and tick Protected), after which a popup asks you to scan your print whenever you access a protected website. Alternatively, you can enter your master password instead. It's important to understand Roboform's cache settings, as the software will remember your logins for a period which bypasses the need to log in every time. You can check the Auto-logoff in Security settings and set it to zero or maybe a minute or two. A useful tip: if the Roboform icon in system tray is wearing dark glasses, then it's deemed 'logged in' and you do *not* need to scan your fingerprints to access websites. You can manually right-click and log off again.

Using Roboform and a fingerprint scanner this way has speeded up access to websites as it requires just a single swipe to log in automatically, and at a low cost it's a worthwhile experiment in biometric security.

That's all for this month's *Net Work*. You can contact the author at **alan@epemag.net** or send comments for possible inclusion in Readout to **editorial@wimborne.co.uk**

# WIN NXP WaRP7

## Next Generation Internet Of Things and Wearable Development Platform From Farnell element14 (RRP £82.00)

The WaRP7 development platform provides IoT and wearable device designers the opportunity to innovate and bring unique products to market, for key target applications such as activity and heath trackers through to smart cities and smart-home appliances.

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The platform consists of a main CPU board and an I/O daughter card which provides a rapid prototyping vehicle for designers, reducing time-to-market and freeing resources to focus on differentiation, which is vital with growing innovations and new products arriving daily in the IoT market.

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**CLOSING DATE:** 28th February 2017

Farnell element14

# CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

## Direct Digital Synthesis and filtering

**FREQUENT** *EPE Chat Zone* contributor ***grahamrounce*** posted about acquiring a signal generator. 'Hi – A Farnell LFM2 [Sine/Square Oscillator] just went for £91 on eBay, about double my budget. I'm going to have to look again at some of the very cheap digitally synthesised ones, but I don't really trust them. If the Farnell one wasn't bought for a museum, does a 70s used one going for so much mean that quite a few other people feel the same? How do they smooth out the steps? Use a different filter circuit for every possible frequency? Probably not. Is there an exhaustive quality comparison, or has anyone here found a noticeable difference in the quality of the output?'

The price of the LFM2 may reflect interest from vintage equipment collectors rather than its technical capabilities, particularly considering the possibility that aging may degrade performance of old equipment. Shortly, we will look briefly at a comparison between the LFM2 and a low-cost (but not the cheapest possible) Direct Digital Synthesis (DDS) signal generator. An alternative to buying a DDS signal generator is to build your own. This may seem daunting, but is made less so by the availability of pre-built DDS modules, usually based on DDS chips from Analog Devices. An SPI bus typically controls DDS chips, which should be reasonably straightforward for someone with microcontroller coding experience (and as this is a popular project, you may find suitable code examples online). Two contributors to the *Chat Zone* discussion on this topic (***g0hjq*** and ***dave_g***) mention building their own DDS circuits.

In his post, ***grahamrounce*** expresses distrust of DDS signal generators, possibly because – as he acknowledges – he does not fully understand how the digital 'stepped' output is filtered to produce a clean analogue signal. We will look at the principles of DDS operation and the filtering requirements later in this article.

### LFM2 comparison

It is likely that a modern DDS-based function generator will outperform the LFM2 in all respects. Looking at one of the cheapest DDS signal generators listed by Farnell at the time of writing (the GW Instek SFG-1003, which is about £140 ex VAT) we can do some basic comparisons. I don't have in-depth knowledge of vintage equipment, so I'm unsure where the LFM2 was positioned in the market when it was new, but comparing it with a basic modern DDS generator will give some idea of the differences at a similar price to that quoted by ***grahamrounce*** for the vintage LFM2. As mentioned in the *Chat Zone* discussion thread, cheaper DDS generators are available, for example, via eBay. Specifications are taken from the Farnell *Instruction Manual for LFM2 Sine/Square Oscillator, Issue 3* and the SFG-1003/1013 3MHz DDS Function Generator data sheet from GW Instek.

The LFM2 has a scale (frequency) accuracy of 2%; for the DDS generator frequency accuracy is much better at 20ppm, and it has a frequency resolution of 100mHz. The frequency stability of the LFM2 is 0.2% short term (eight hours) whereas it is 20ppm for the DDS generator, although a time period is not given in the data sheet linked by Farnell. The DDS generator aging stability is given as 5ppm per year, but long-term stability is not specified for the LFM2.

In general, the frequency accuracy and stability of DDS signal generators depends on the crystal oscillator used to derive the clock to the DDS circuit and therefore very accurate and stable frequencies are possible. Some modern analogue signal generators use digital locking to achieve better frequency accuracy than simply using a free running oscillator. The LMF2 manual states that a signal can be fed into the oscillator to lock the instrument to an external frequency.

### Signal quality

Distortion in the LFM2's sine output is 0.5% from 10Hz to 100kHz and 5% worst case over the full 1Hz to 1MHz range. For the DDS generator it is –55dBc (0.2%) from 0.1Hz to 200kHz, –40dBc (1%) from 0.2MHz to 2MHz, –35dBc (2%) from 2MHz to 3MHz. The example DDS signal generator produces a less distorted sinewave than the LFM2 – and does so over a wider range at both the low and high ends.

The DDS generator's signal quality reduces as frequency increases, whereas the LFM2's signal quality is poorer at *both* the low and high ends of its frequency range. In general, DDS signal generation produces better quality waveforms when the clock frequency is much higher than the output signal frequency, so quality will reduce with increased frequency. The term 'dBc' in the DDS distortion specification is signal amplitude relative to carrier (c) in dB; here 'carrier' refers to the wanted signal output.

The LFM2 generates sine and square waves. In addition to this, the example DDS signal generator produces triangle waves. More advanced DDS equipment adds further waveforms such as ramps and the ability to generate programmable arbitrary waveforms. DDS makes other functions such as frequency sweeps, frequency and phase modulation, and generation of multiple signals with very precisely controlled phase differences straightforward to implement, and such features are available on more advanced function generators.

### How not to do DDS

If you ask someone to design the simplest possible digital waveform generator without giving it too much thought or analysis they may well come up with something like the system shown in Fig.1. The digitised waveform is sent to a DAC at the clock frequency $f_c$. If the sequence generator goes through $N$ digitised steps for the

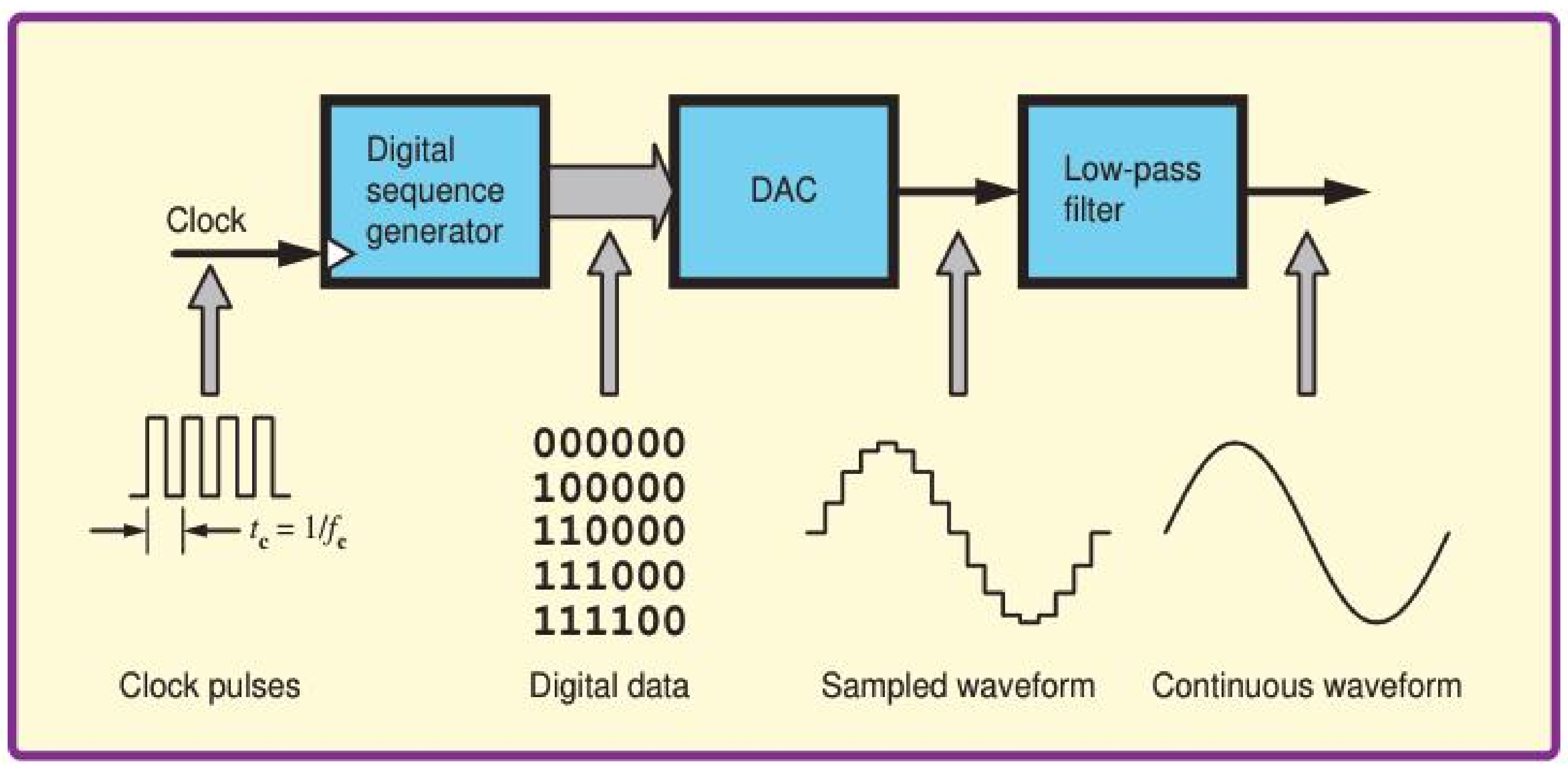

*Fig.1. Block diagram of a circuit for generating waveforms digitally*

complete output waveform cycle, then we have an output frequency ($f_o$) of:

$$f_o = f_c/N$$

If we store the waveform data in memory with $n$ address lines we can have $2^n$ samples, so $N = 2^n$.

The stepped analogue waveform from the DAC is low-pass filtered to produce a smooth analogue waveform – this is referred to as the reconstruction filter. The filter should pass signals at the required signal frequency but significantly attenuate higher frequencies. More specifically, the cut-off frequency of the filter, $f_{cut}$, needs to conform to:

$$f_{sigm} < f_{cut} < (f_s - f_{sigm})$$

where $f_{signm}$ is the maximum frequency in the sampled data signal – this is simply the output frequency for sinewave generation. $f_s$ is the sampling frequency, which is the clock frequency in the system in Fig.1.

There are a couple of major challenges in the design shown in Fig.1. First, the system requires a variable frequency clock if a variable output frequency is required, which means that it cannot use a straightforward, but high-accuracy and high-stability, crystal oscillator directly as the clock source. Second, changing the clock frequency changes the filtering requirements. As mentioned above, the filter cut-off frequency is dependent on the sample (clock) frequency.

If a fixed filter is used in the system shown in Fig.1, the ADC waveform will not be correctly filtered at all frequencies within the range that can be generated. This may be what ***grahamrounce*** was concerned about when considering DDS generation. Fig.2 shows an example where the filtering is working correctly. Here, a sixth-order filter with a cut-off about 1.5kHz is used with a 900Hz generated signal and 11kHz sample rate. In the waveform in Fig.3 the sample rate is reduced by a factor of 10 to produce a 90Hz signal, but the filter has not been changed. The filter cut-off frequency is too high and the output is not correctly filtered to produce a clean sinewave.

## NCO

Designing a filter that correctly tracks the sampling frequency over a wide range is much less straightforward than using a fixed cut off frequency and therefore undermines the convenience of the system shown in Fig.1 for wide-frequency-range digital waveform generation. The problem can be overcome using what is known as a 'numerically controlled oscillator' (NCO). An NCO-based DDS uses a fixed clock frequency and sample rate, and therefore requires a fixed cut-off reconstruction filter and can be clocked from a fixed frequency crystal oscillator.

An NCO can also provide very rapid frequency changes in the generated waveform, which would be difficult to achieve if the filter characteristics had to be changed as well as the frequency. This ability is referred to as 'frequency agility' and is an important advantage of DDS. Phase-locked loops can also be used to generate accurate-frequency, high-quality sine waves, but due to the time it takes the PLL to lock to a new frequency they cannot change as fast as NCO-based DSS generators.

Digital generation of a waveform can be represented as shown in Fig.4. The data points that make up the waveform are shown as red dots around a circle – the waveform is repetitive, so we go once round the circle for each cycle of the waveform. For a sine wave, the height of the dot above the line is equal to the data value (amplitude at that point – the arrow on Fig.4 shows the link between an example point on the circle and waveform) but the circle of points could more abstractly represent other data values. The sampling frequency is related to the spacing of the red dots on the waveform in Fig.4; this is also indicated by the white dashes at the bottom of the figure.

It is straightforward to change the waveform frequency by changing the sample rate. Fig.5 shows a situation in which the sample rate has been doubled to double the waveform frequency. Exactly the same sample data is used, but at a faster rate. This is how we need to operate the circuit in Fig.1, with the resulting problems we have already discussed.

## Skipping round the phase wheel

An alternative way to change the waveform frequency is to skip some of the sample points as we go round the circle. For example, we can keep the same sample rate as Fig.4, but only use alternate data points (dots on the circle), as shown in Fig.6. This doubles the waveform frequency *without changing the sample rate*. The fact that the sample rate is the same means that we can use the same fixed low-pass filter without degrading the quality of the lower frequency waveforms.

As noted earlier, if we store the waveform data in a memory with $n$ address lines we can have a total of $2^n$ waveform samples in one cycle. If we generate our output using every sample we get an output frequency of $f_c/2^n$, as with Fig.1 and Fig.4. However, if we skip alternate memory locations the frequency doubles to $2f_c/2^n$, as in Fig.6.

We can skip more samples to get higher frequencies and, in general, if we move forward $M$ stored samples per output sample, then the output frequency is:

$$f_o = Mf_c/2^n$$

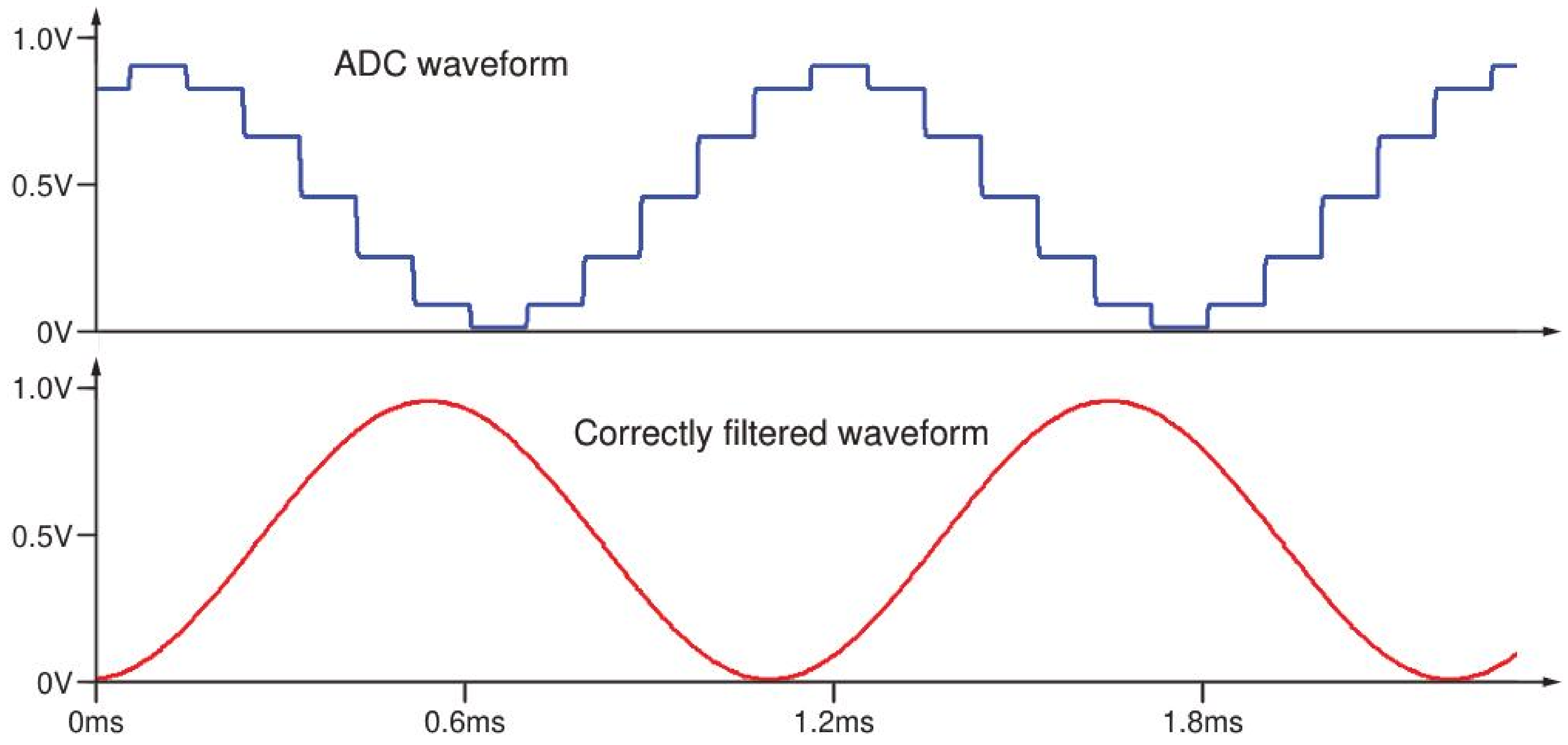

*Fig.2. Digitally generated sine wave with correct filtering; approximately 900Hz, 1Vpk-pk*

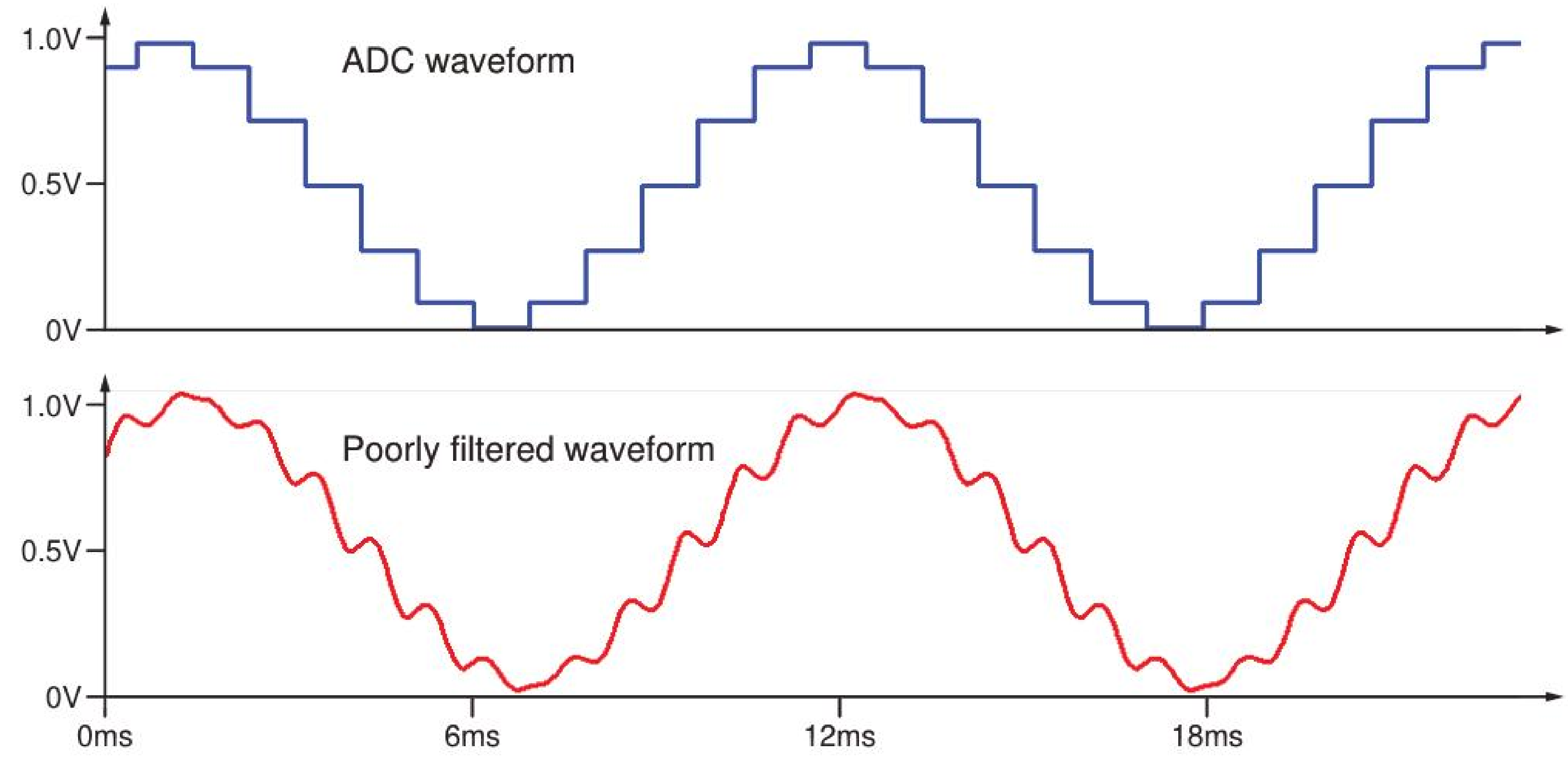

*Fig.3. Digitally generated sine wave at lower frequency than that in Fig.2 (approximately 90Hz 1Vpk-pk), but with the same filter. The filtering is inadequate and a smooth sine wave is not produced*

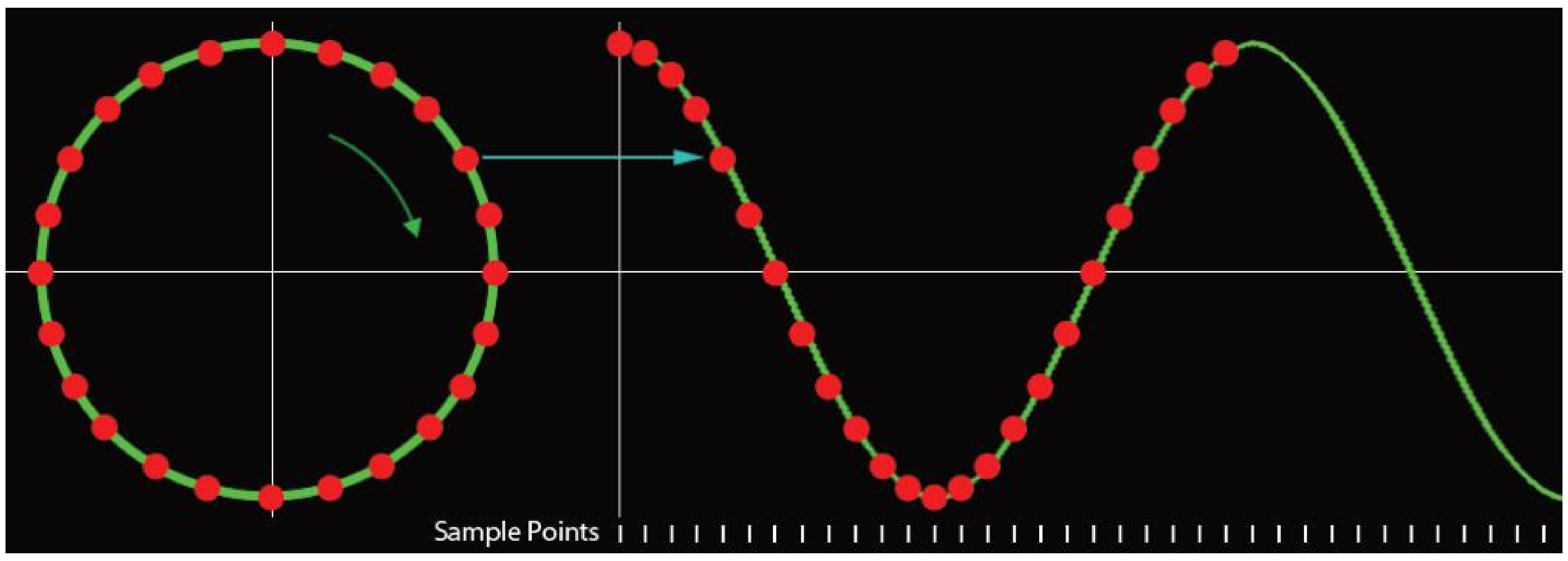

*Fig.4. The points on a circle generating a sine wave*

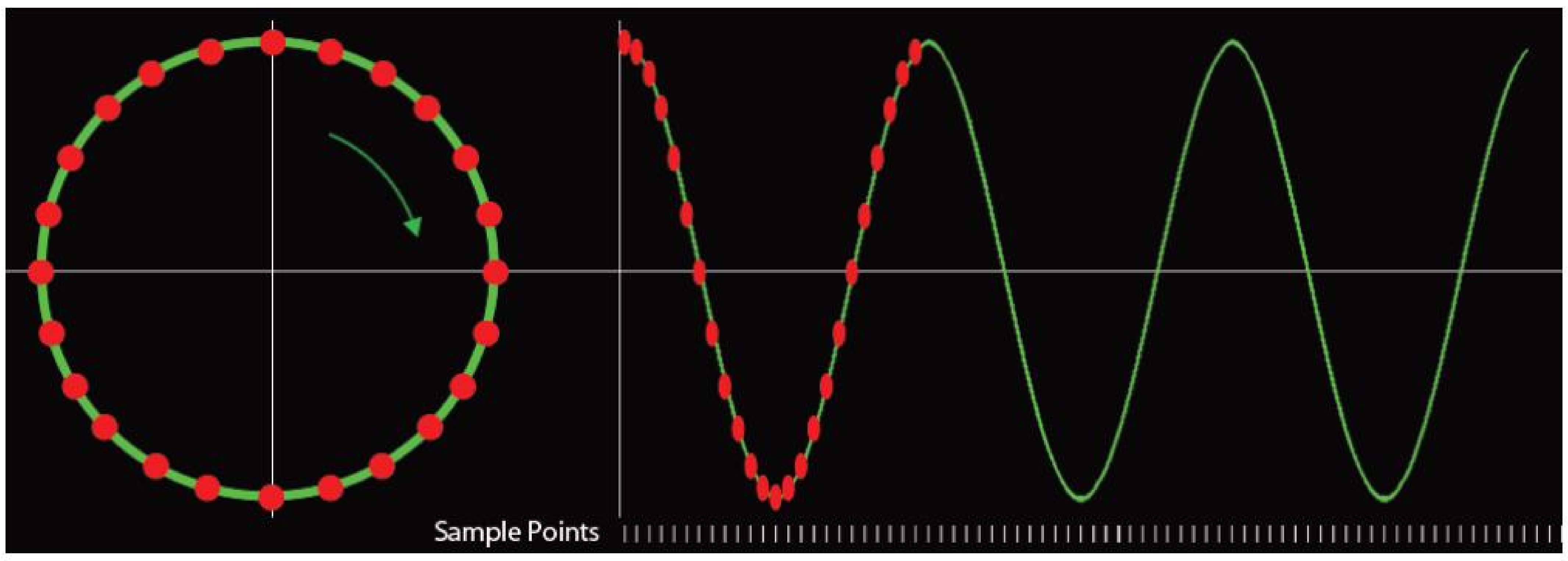

*Fig.5. Using the same sample data at a higher sample rate increases the waveform frequency*

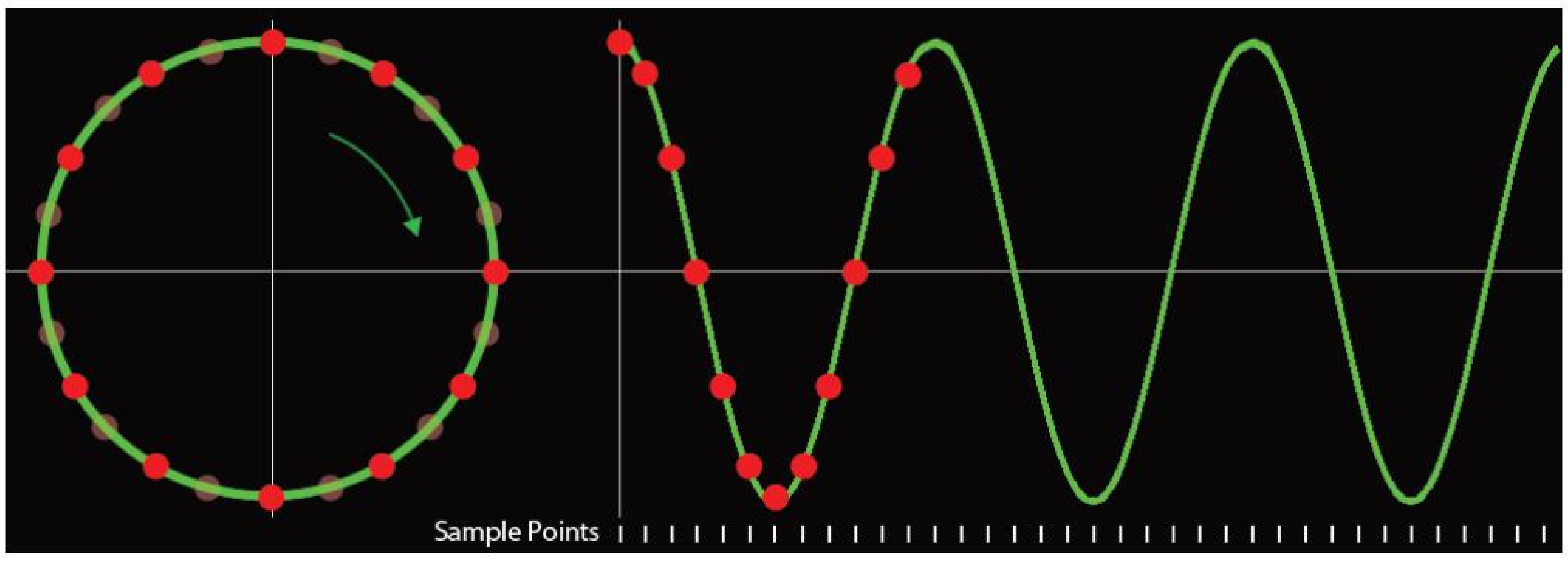

*Fig.6. Skipping some of the sample points allows the higher frequency waveform from Fig.6 to be produced using the sample frequency as used in Fig.4*

This is like moving forward by *M* dots round the circles in Fig.4 and 6 to get the next value to use. Remember, in this approach the output samples are produced at the same rate, irrespective of how far we step to get the next value.

The fact that the output frequency is $Mf_c/2^n$ is important, because although it depends on the clock frequency, unlike for the system in Fig.1, it is not wholly dependent on it. If we can vary *M* in our circuit design we do not have to change $f_c$ to vary the output frequency, so we can easily use a fixed-crystal-oscillator-based clock. As the sample frequency is fixed at the clock frequency we can use a fixed low-pass filter. We overcome the problems with the system in Fig.1.

*M* corresponds to the angle ($\varnothing$) that we move round the circle to get to the next sample point. This is a phase shift in waveform terms so *M* is referred to at the 'delta phase' value. *M* is also called the 'tuning value' because it sets the output frequency.

## DDS system

A block diagram of a digital waveform generator using the principles just outlined is shown in Fig.7. The value of *M* is loaded into the delta phase register to set the output frequency. For each sample point (system clock cycle) the value in the delta phase register is added to the current waveform location, which is stored in the phase register. In terms of the circles and dots in Fig.4 and Fig.6 the phase register indicates which dot we are currently using for the output sample and the delta phase register determines how many dots we will go forward to get the next output sample.

The phase register is used to address the waveform sample data memory, converting the phase value to the waveform amplitude at that point of its cycle. This value is passed to a DAC and low-pass filter to convert it to an analogue waveform. Loading a new value of *M* into the delta phase register will change the output frequency immediately on the next system clock cycle. Thus the frequency can change very quickly and at any point on the waveform cycle.

Looking at Fig.4 and Fig.6 it might seem that the number of possible output frequencies is very limited, that is the frequency resolution is poor. Indeed this is true for the example presented in Fig.4 and Fig.6, but a real implementation is not limited by the need for a clear diagram and can have many more available sample points (effective dots round the circle). For a 32-bit phase register the frequency resolution is one part in four billion. Typical DDS chips use 24 to 32-bit phase registers. In general, frequency resolution is $f_c/2^n$ for a clock frequency of $f_c$ and an *n*-bit phase register.

So far we have presented a simplified overview of NCO-based DDS operation. In practice, a number of other details have to be considered. Usually the full number of bits of the phase register is not used to address the sample memory. Truncating the address into the memory adds a small error to the waveform that appears as noise in the output. Typically 12 to 19 bits of the 24 to 32-bit phase value are used. The number of bits in the DAC may also be less than the number of bits in the sample memory address (typically 12 to 14-bit DACs are used); again, this adds a small error as quantisation noise in the output. For symmetrical waves such as sinewaves the full waveform may not need to be stored. To achieve very high clock rates a DDS chip can use on-chip clock frequency multiplication (in common with other chips such as microcontrollers).

## Reconstruction filter

The theory of sampled data systems shows that when the sampled data is output to 'reconstruct' the original waveform, copies of the original signal shifted to higher frequencies are produced, along with the original signal. The same applies when we digitally generate the samples rather than having captured them from an original analogue source. The frequency-shifted copies, called 'images', introduce unwanted components in the spectrum of the output signal, thus causing distortion.

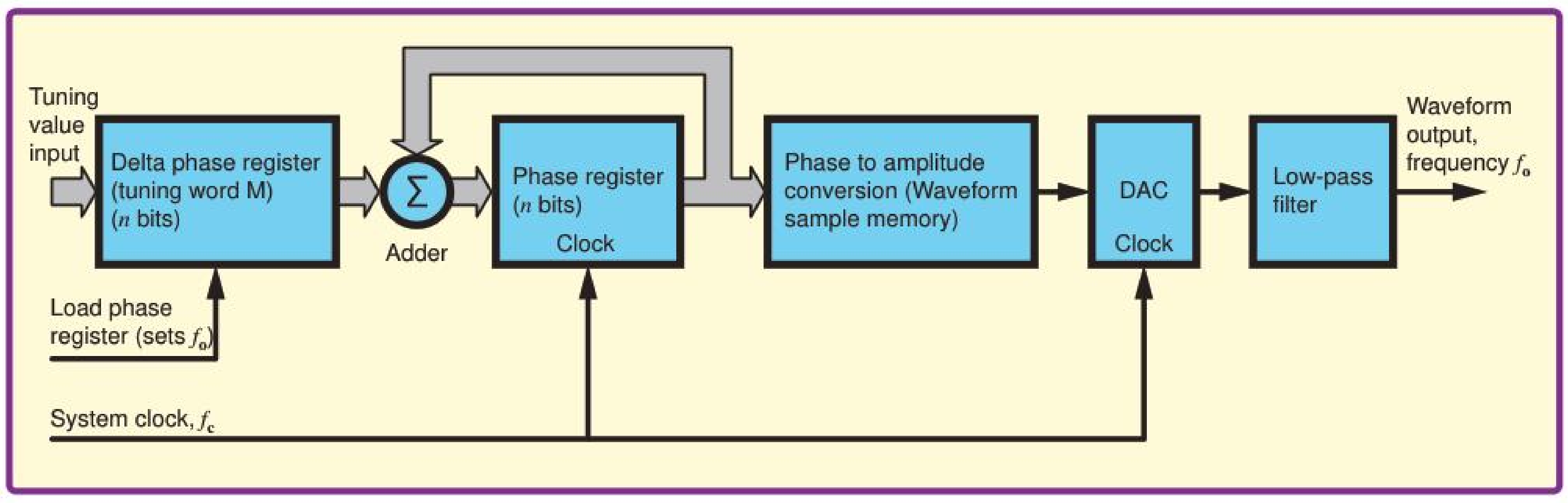
Tuning value input
Delta phase register (tuning word M) (n bits)
Σ
Adder
Phase register (n bits)
Clock
Phase to amplitude conversion (Waveform sample memory)
DAC
Clock
Low-pass filter
Waveform output, frequency $f_o$
Load phase register (sets $f_o$)
System clock, $f_c$

*Fig.7. Block diagram of a DDS waveform generator using a numerically controlled oscillator.*

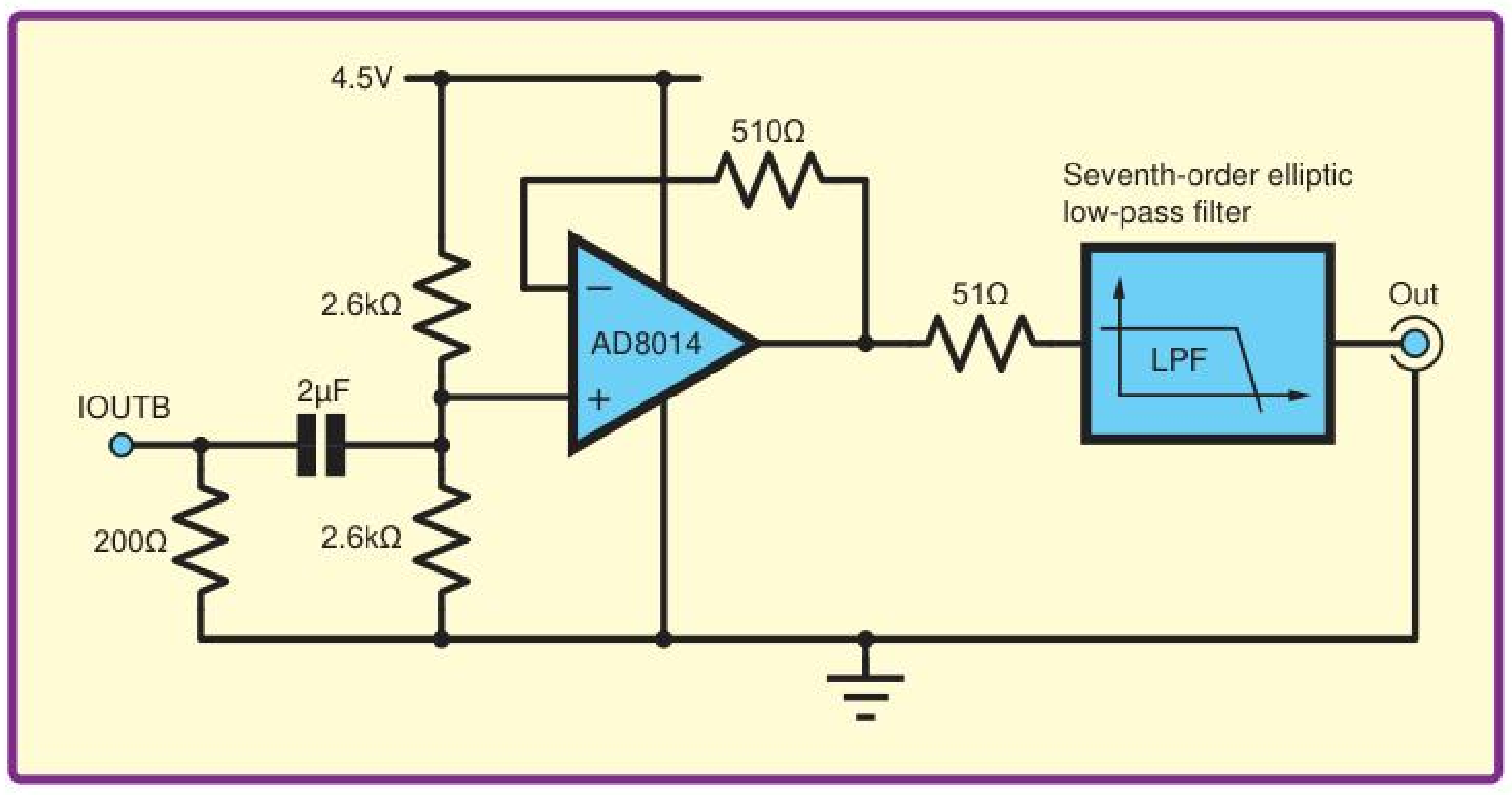

*Fig.8. Example DDS output and filter circuit. Based on a schematic from Analog devices in Circuit Note CN-0304 for a circuit using the AD9834 75MHz DDS.*

A low-pass reconstruction filter must remove these higher frequency components if we are to obtain a good quality output waveform. The requirements for the cut-off frequency are the same as those stated earlier in the discussion for Fig.1.

The DAC in the DDS circuit acts as a low-pass filter with respect to the pure sample data, but it does not remove all image frequencies (hence the 'stepped' output). The images in the DAC output follow an amplitude envelope with a sin($x$)/$x$ function, where $x$ is related to the ratio of signal to clock frequency. Thus, a further low-pass filter is required to achieve a good output signal.

Analog Devices, who manufacture a large range of DDS chips, typically use seventh-order passive LC elliptic filters (also known as 'Cauer filters') in their example designs and DDS application notes. Elliptic filters can provide very sharp cut-off and independently adjustable passband and stopband ripple. These filters should be implemented with high quality SMD components. Factors such as series resistance and self-resonance are important because the filter must perform well to very high frequencies (several times the DDS clock frequency). PCB layout is also an import factor in filter performance. Analog Devices have published technical documents such as *Application Note AN-837 and Circuit Note CN-0304*, which discuss DDS filtering in depth.

### Examples

A couple of example DDS output and filter circuits are shown in Fig.8 and Fig.9. In common with many DACs, the output from DDS chips is typically a differential current – that is there are two current outputs (labelled IOUT and $\overline{\text{IOUT}}$) which change in opposite directions as the signal changes. These can be converted to a differential voltage by connecting a resistor from each output to ground or a supply, as specified in the datasheet. It is possible to use just one output channel to keep deigns simple (as in Fig.8), but this will reduce signal quality. The differential voltage signal from the DDS chip plus resistors can be converted to a single-ended signal using a suitable transformer (as in Fig.9) or a differential-input amplifier. The elliptical filter in Fig.8 has the same structure as that in Fig.9, but with different component values due to the different clock frequencies of the DDS chips.

With a well-designed and implemented output filter DDS chips can produce very high quality sine wave outputs. The quality of DDS-based lab equipment will of course vary with the quality of design, components and PCB layout and overall construction standard. However, moderate-performance DDS systems can be produced with quite a low component cost, so low-cost equipment of reasonable quality should be feasible if production costs are modest.

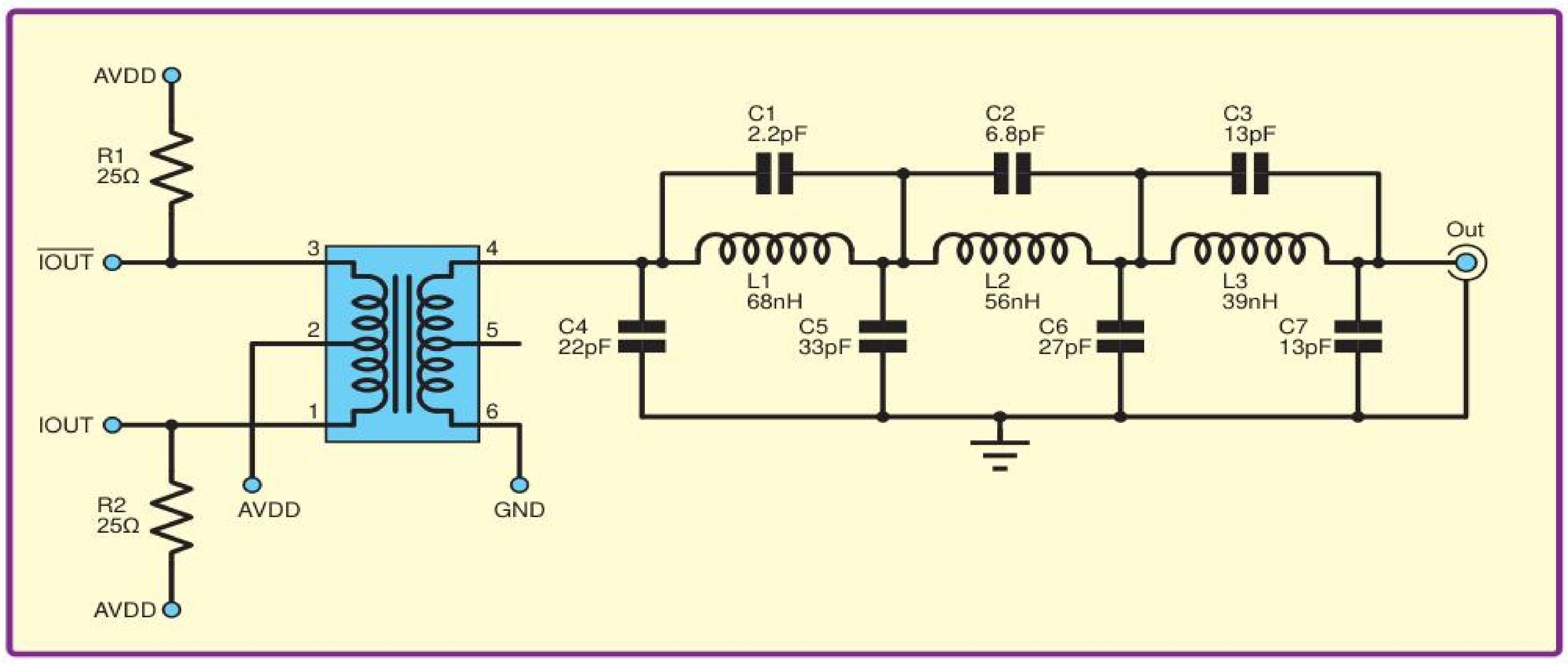

*Fig.9. Example DDS output and filter circuit. Based on the reference design from Analog Devices in the datasheet for the AD9954 400 mega-samples per second DDS*

## Corrections

### Bipolar regions of operation table

We have suffered from a few typographical gremlins recently. In last month's article on transistor switching, the junction bias conditions were swapped for the reverse and forward active regions. Thanks to *Chat Zone* contributor ***James*** for pointing this out.

**Corrected Table 1: Bipolar transistor regions of operation**

| Base-emitter junction bias | Base-collector junction bias | Region of operation | Comment |
|---|---|---|---|
| Forward | Forward | Saturation | Switch ON |
| Reverse | Forward | Reverse Active | Poor amplifier, specialist uses |
| Forward | Reverse | Forward Active | Good amplifier |
| Reverse | Reverse | Cut-off | Switch OFF |

### Current sensor equation

In the January 2017 article there were a couple of typographical errors in the first equation relating to the high-side current-sense circuit by Bob Bell and Jim Hill (Fig.9 in that article). The subscript for the first $I$ should be 2, not 1, and the last term ($I_SR_S$) was incorrectly repeated on a second line. The corrected equation is:

$$-(I_2 + I_3)R_1 - V_{BE1} + V_{BE2} + I_2R_2 + I_SR_S = 0$$

The current in $R_1$ is $I_1$ which is equal to the sum of $I_3$ and Q1's collector current, which is $I_2$ from the mirror action. In the correct version the $-I_2R_1$ and $I_2R_2$ terms cancel, as described in the article ($R_1 = R_2$) to give the second equation ($-I_3R_1 + I_SR_S = 0$). Thanks to ***Godfrey Manning*** (G4GLM) for his email about this.

# PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

## PICs and the PICkit 3: LED binary clock

**FOR THE LAST** few months, we've been focused on the beginners guide for the PICKit 3 Low Pin Count Demo board. This month, I want to take a break and do something a little more adventurous. While it is not absolutely necessary to have read any of the previous articles, they will definitively help. I want to use as much of the beginners guide as possible because this will help in understanding how PICs work and how to design something from what we've already learnt.

This month, we'll build an *LED Binary Clock*, which tells the time in binary. I'm going to use what we've learned from Lesson 3: Rotate, Lesson 4: Analog to Digital Conversion, Lesson 5: Variable Speed Rotate, Lesson 6: Debounce, Lesson 8: Pulse Width Modulation and Lesson 9: Timer0. I recommend having a look back at these lessons as a refresher before continuing.

### Project planning

Benjamin Franklin supposedly said, 'If you fail to plan, then you plan to fail'. I agree! Any successful project starts with a clear and focused idea of what you want to achieve. So for this project I will start with what I want the clock to do; our 'specification', which we can refer to and use to ensure we're on the right path.

- Create an *LED Binary Clock*
- Use as much of the PICKit 3 Demo Board Tutorials as possible
- Use the PIC16F1829
- Show the time as a 12-hour clock with one-minute resolution
- Indicate ticking seconds
- Be able to adjust the brightness of the LEDs
- Be able to change the time
- Be able to program the PIC
- Power from two AA batteries
- Use as few components as possible
- It has to look good!

Now that we have a rough idea of the specification, the next part is figuring out how we go about designing and building this device. Starting with the clock display, if we wanted to build a normal 12-hour clock using LEDs, then we would need quite a lot of LEDs. We would need 12 alone for the hours, five for the tens of minutes and a further nine for the minutes. This means a total of 26 LEDs and I haven't even included how to show the seconds. There aren't enough GPIO connections to control each of these LEDs and powering them straight from the PIC would cause problems.

This is where binary comes in. Binary is a two-value numbering system using only ones (1s) and zeroes (0s). By comparison, decimal is a 10-value numbering system, which uses 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9. Fig.1 shows a conversion table converting numbers from 0 to 12 into 4-bit binary. We can see from this table that we can represent any decimal number from 0 to 12 using four binary digits. Each digit is represented by one LED, '0' for off and '1' for on. For example, take the number 6 in decimal, this is '0110' in binary, which could be represented with four LEDs – the first and last LED off and the two middle LEDs on.

Fig.2 shows the binary representation of the 'time' 6:53. The three columns (left to right) represent hours, tens of minutes and minutes, with the least-significant bit (LED1) at the bottom. Red indicates an LED is lit, representing a '1' and black shows an LED is off, representing a '0'. The first column (hours) covers 0 to 11 and here displays a binary representation of the decimal number 6.

The second column covers tens of minutes (10, 20, 30, 40 and 50). In the Fig.2 example the binary number displayed is '101', which is '5' in decimal. Since this is tens of minutes this represents 50 minutes. Notice how we only use three LEDs in the second column. The largest possible number that could be used here is '5' for 50, which means a potential fourth LED would be redundant because it would never be lit. The third column covers minutes from 0 to 9, and the binary number displayed is '0011', which is '3' in decimal.

| Decimal | | Binary | | | |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 1 |
| 0 | 2 | 0 | 0 | 1 | 0 |
| 0 | 3 | 0 | 0 | 1 | 1 |
| 0 | 4 | 0 | 1 | 0 | 0 |
| 0 | 5 | 0 | 1 | 0 | 1 |
| 0 | 6 | 0 | 1 | 1 | 0 |
| 0 | 7 | 0 | 1 | 1 | 1 |
| 0 | 8 | 1 | 0 | 0 | 0 |
| 0 | 9 | 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 | 1 | 1 |
| 1 | 2 | 1 | 1 | 0 | 0 |

*Fig.1. Decimal-to-binary conversion table*

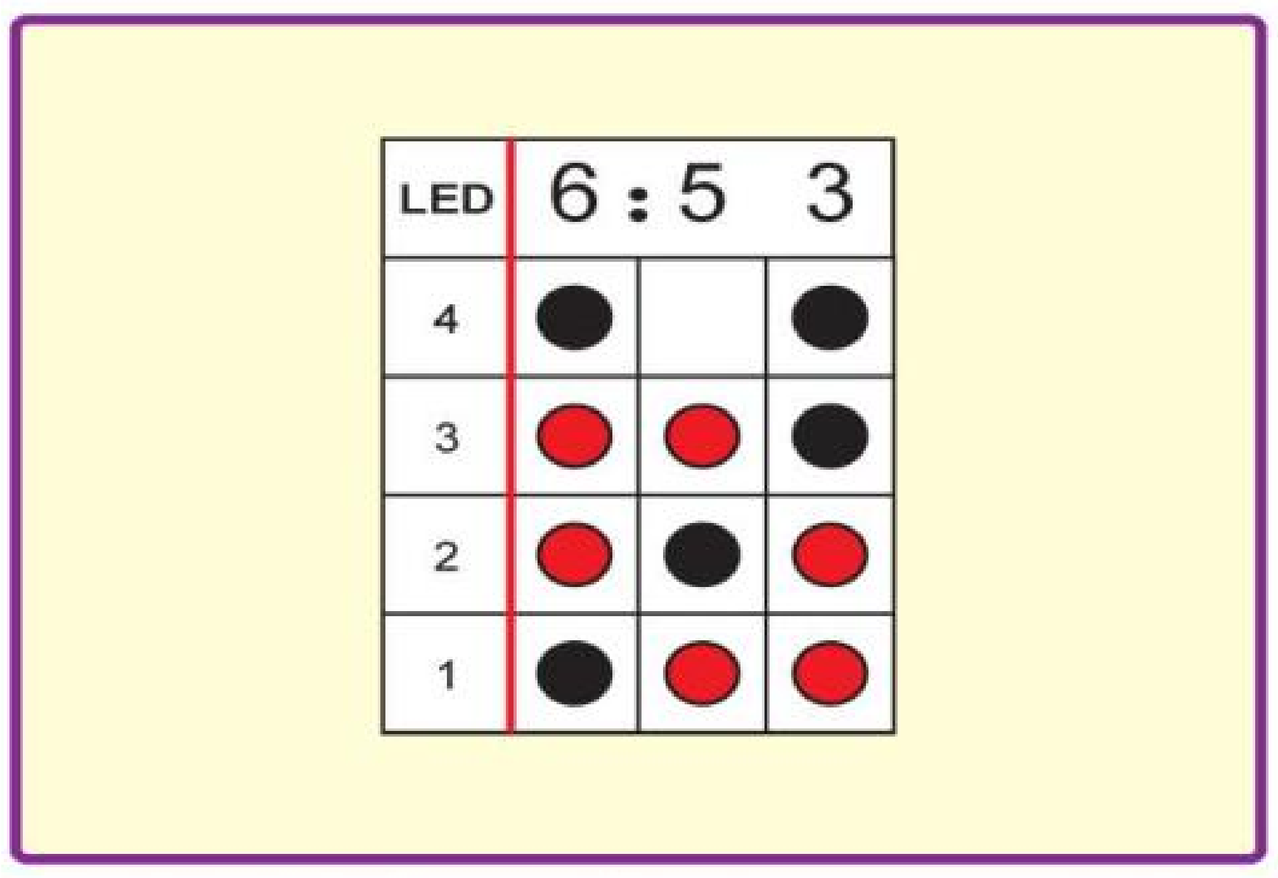

*Fig.2.* LED Binary Clock *representation, rows and columns*

This arrangement allows the clock to display all possible times from 0:00 to 11:59, after which it reverts to 0:00 again.

It would be useful to show some indication of seconds passing, and this can be easily done with a single LED, which cycles on and off once a second.

In total, this means we now use four LEDs for the hours, three LEDs for the tens of minutes, four LEDs for the minutes and one LED to show seconds; 12 LEDs in total. This is less than half the number we first considered and is much easier to control.

### Other functions

Now we have an idea of how the *LED Binary Clock* will show time, lets consider the other functions we want to implement.

### Brightness control

In order to change the brightness of the LEDs, we will need some sort of adjustable input and some method to control the brightness. From the Demo Board, we used a potentiometer as the adjustable input. A 22kΩ potentiometer will work here. One side will be connected to the input voltage (battery voltage) and the other side will be connected to ground. The output from the potentiometer will be connected to the 10-bit ADC pin on the PIC, as shown in the schematic in Fig.3. By adjusting the potentiometer we can get ADC values from 0 to 1023. In the software, we take this value and we use it to control a PWM signal connected to an NPN transistor (which we'll cover next month). This transistor will be placed on the low side (cathode) of all the diodes. Normally the diodes would be connected straight to ground. By placing this transistor in series, we can turn all the transistors on and off via their ground connection. The advantage of using PWM is that we can turn the LEDs on and off fast enough to effectively dim their brightness without flicker.

### Changing the time

In any clock, you want to be able to change the time. For simplicity, two momentary buttons will suffice. One button will cover incrementing the hours and the other button will increment the minutes. Using what we learned in the debounce lesson, we make sure there's a small delay between each button press (we will see this in the software covered next month).

### Programming the device

This is a feature that can be easily forgotten, but is absolutely necessary. In order to connect up the PICKit3 programmer and upload the software to the device, we need a 6-pin programming connector.

### Components

Now we have a better idea of how we're going to implement all of the functions, we now need to know what to purchase. The following is a list of everything you will need to get up and going.

*Semiconductors*
1 × PIC16F1829-I/P (make sure it's the 20 lead PDIP part) (IC1)
12 × 5mm wide LEDs, any colour will do (D1-12)
1 × BC548C NPN transistor (TR1)

*Passive components*
12 × 220Ω resistors (R1-12)
3 × 1kΩ resistors (R13, 15, 16)
1 × 10kΩ resistor (R14)
1 × 22kΩ Potentiometer (VR1)
1 × 100nF ceramic capacitor for decoupling (C1)

*Hardware*
1 × Battery holder with switch (BT06092 from Pro-Power)
2 × AA batteries (1.5V, non-rechargeable)
2 × Momentary switches (S1,2)
Red, black, blue, green, white single-core wire
4 × Plastic M3 screws and plastic stand offs
1 × Veroboard (16 holes across, 38 holes down)
1 × DIL IC Socket (2227-20-03-07 from Multicomp or equivalent)
1 × 6 pin header (2213S-06G from Multicomp or equivalent) (J1)

*Miscellanous*
PICKit 3 programmer
Multimeter for debug

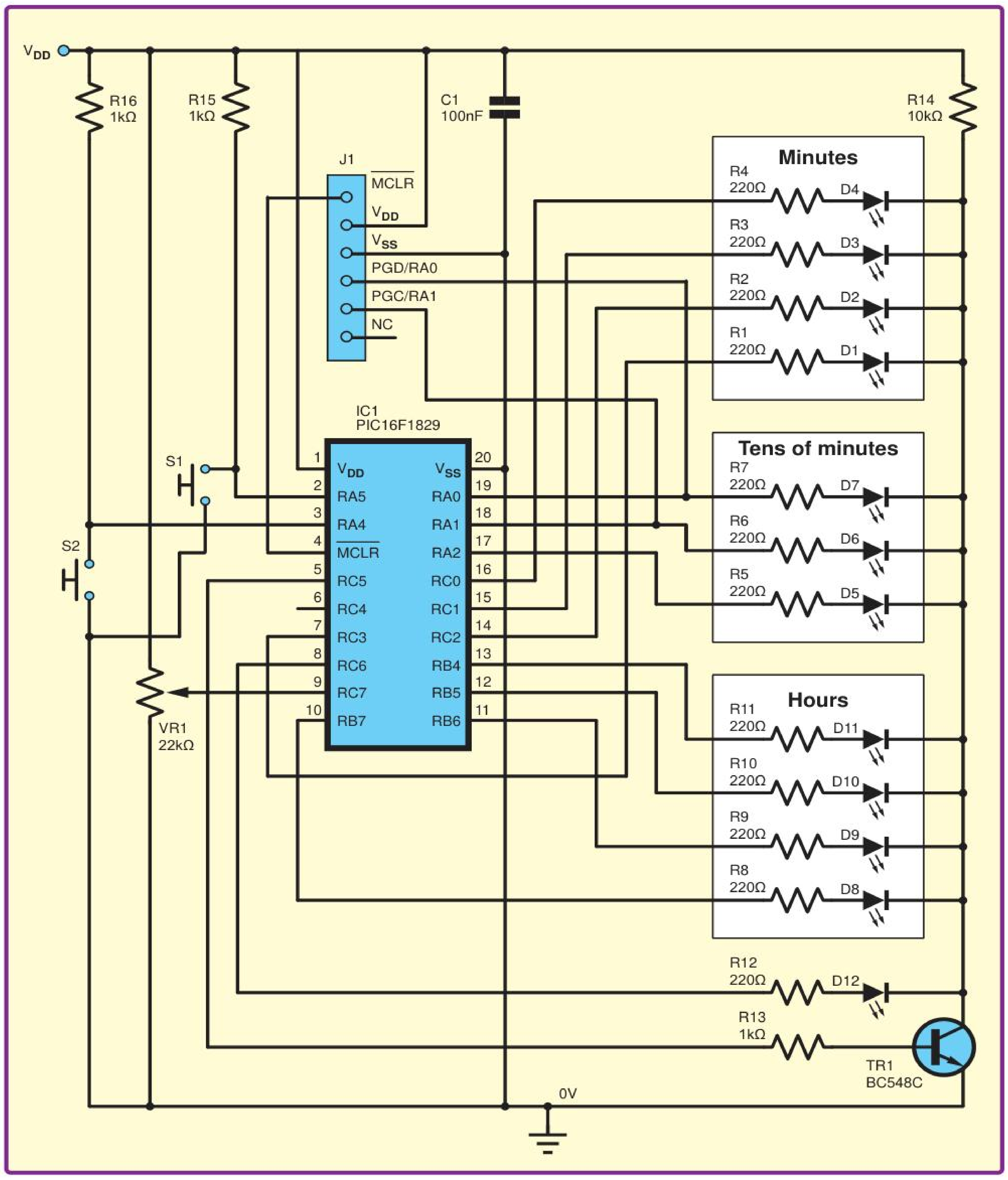

*Fig.3.* LED Binary Clock *schematic*

While I haven't used a DIL IC socket in my own design, I do recommend them because you can easily swap out the PIC if necessary, instead of soldering it straight onto the Veroboard. Any 3V supply will suffice, but I like to use a double-AA battery holder with switch (like the one specified above). It's very handy for turning the project off, when not needed. For the LEDs, I've used all red LEDs for the hours, tens of minutes and minutes, and a green LED for the seconds. You can use any colour you want here, so feel free to express yourself.

### Schematic

Fig.3 shows the schematic for the *LED Binary Clock*. I've grouped the LEDs by column: hours, tens of minutes and minutes. A single PORT in the PIC controls each column:

- PORT B covers the first column; the hours (RB4, RB5, RB6 and RB7)
- PORT A covers the second column; the tens of minutes (RA0, RA1, RA2)
- PORT C covers the third column; minutes (RC0, RC1, RC2 and RC3).

This simplifies the software. For example, in order to change the minutes, we only need to write to the lower four bits of PORT C, instead of some complicated mapping (I will cover this more in the software description next month).

Note the 1kΩ pull-up resistors connected to buttons S1 and S2. These ensure that when the button is pressed, $V_{DD}$ (the supply voltage) isn't shorted to ground. It also ensures when the button is not pressed that the signal to the PIC is logic high, instead of floating (which can be an undetermined state, sometimes logic high, sometimes logic low).

Also note the NPN transistor (TR1) attached to the cathode side (low side) of all the diodes. Normally these would be connected straight to ground, but in this case we can control the brightness of all the diodes by using PWM on this transistor.

The 220Ω resistors on each diode limit the current to each diode for protection. There's also a 10kΩ resistor connecting the low side of the diodes to $V_{DD}$. This ensures that when TR1 is turned off, the low side is pulled high, ensuring the diodes are off. When the NPN transistor is turned on, this resistance is high enough to allow the diodes to turn on.

### Breadboard construction

Now that we've got all of the components it's time to start building the project. Fig.4 shows the Veroboard (component side on the left and the

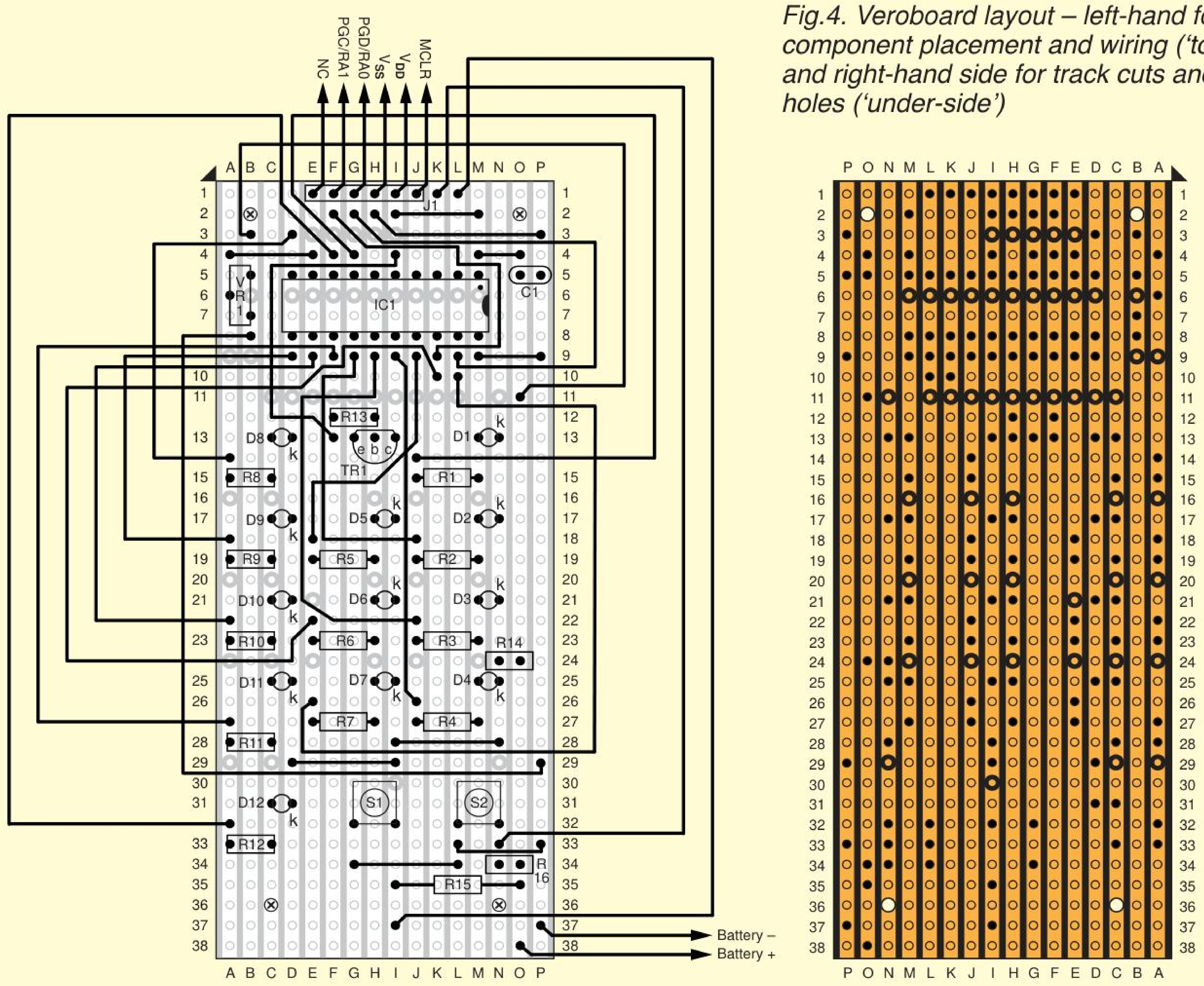

*Fig.4. Veroboard layout – left-hand for component placement and wiring ('top-side') and right-hand side for track cuts and drill holes ('under-side')*

copper side on the right). You may need to cut the Veroboard yourself from a larger piece. I recommend running a sharp blade back and forth along a line of holes. Once you've done this enough, the board should snap apart easily. Be careful using a blade of any type.

In the four corners, we have mounting holes for the plastic M3 screws and stand offs. These will stand the board up vertically. Use a 3mm drill bit to cut these. The orange lines represent the conductive copper tracks. These need to be cut in order to separate signals from each other. Large circles dividing the copper track show the cuts. To make track cuts I recommend using a sharp 2.5mm drill bit and screwing into the board at the hole, not all the way through, just enough to remove the copper. You can also use a blade, but I don't think it looks as nice. Use a multimeter to make sure the two sides of the cut track are now disconnected form each other.

Once all the cuts have been made and holes drilled, we can flip the board over and start placing the components. The left-hand side of Fig.4 shows the component placement and wiring for the board.

## Wiring

The wiring is often the most annoying part and where things usually go wrong. It is best to compare Fig.4 against the schematics in Fig.3 to understand what each wire is connecting. I find it easier to make the cuts first and then add the wire links, You can now check with a multimeter that all connections/disconnections are as they should be.

## Components

Next, place the big components, starting with the DIL socket for the PIC, then the diodes, resistors, buttons, capacitor and potentiometer. Remember, when placing TR1, its flat side faces the PIC. You may need to bend the pins here to get them to sit in the holes. Make sure the pins don't touch each other.

When placing the diodes, remember the cathode is the shorter pin and should line up with the small 'k' marked on the top side in Fig.4. When inserting the PIC16F1829 in the socket make sure the pin 1 marking (dot in the corner) matches the location of the dot in Fig.4.

## Final product

The completed hardware should look like Fig.5. You may notice I've used different coloured wiring for different connections. I like to use red wire for $V_{DD}$ and black wire for 0V. I've also used blue wire to connect up all the LED control signals and white wire to connect up the two buttons and programming pins PGC and PGD. It's not necessary to do this, but it can make wiring a little easier.

Can you tell what time I took the photo?

## Next month

We've built the hardware and now we're ready to program the new board. Next month, I'll cover the software to run the *LED Binary Clock*.

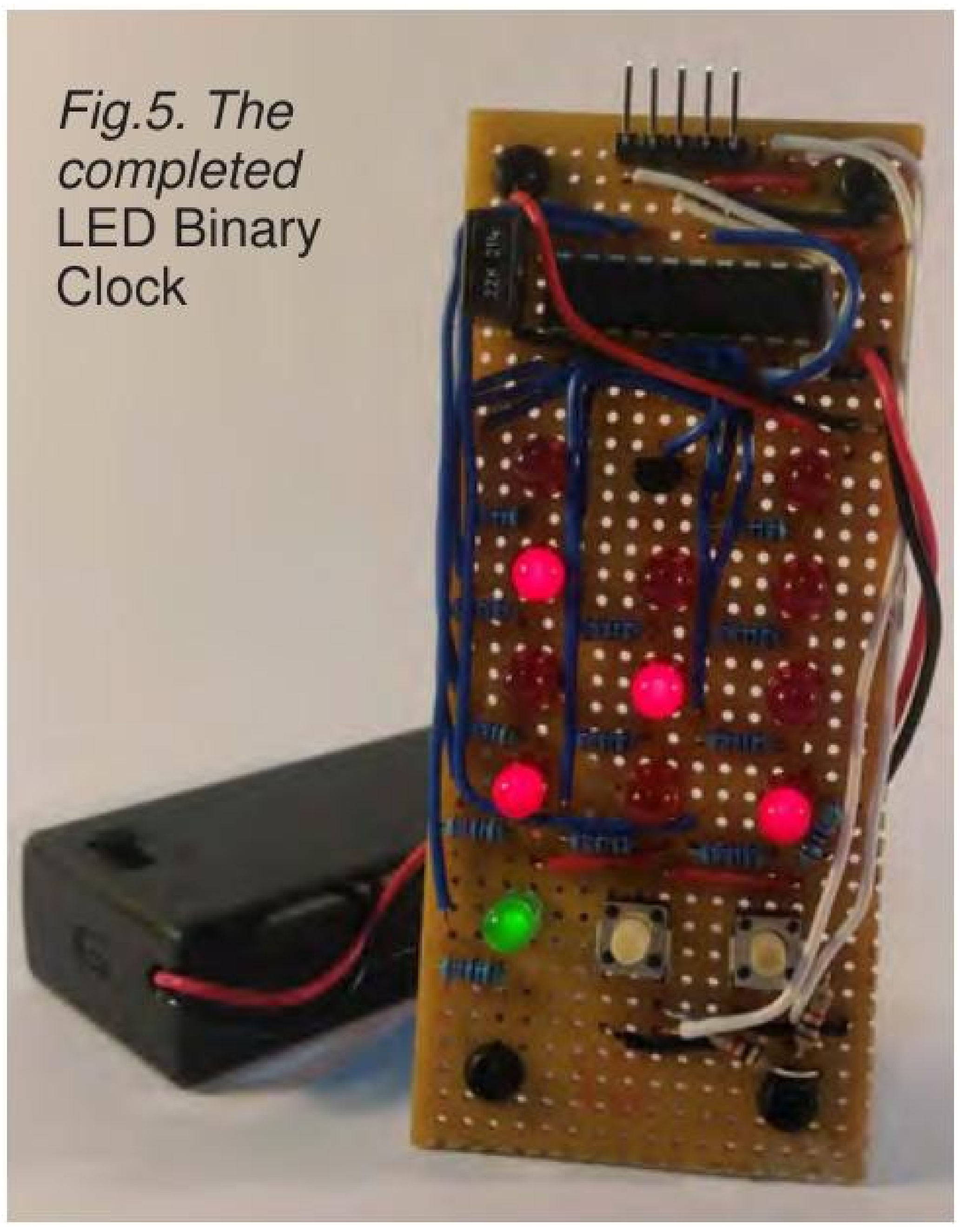

*Fig.5. The completed* LED Binary Clock

**Not all of Mike's technology tinkering and discussion makes it to print.**

**You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com***

# Development Tool of the Month!

## PIC24F Curiosity Development Board

Part Number
DM240004

### Overview:

The PIC24F Curiosity Board is a low-cost development platform with an integrated programmer and debugger and easily expandable with a mikroBUS interface to utilise Click Boards for customising your application. This board features the PIC24FJ128GA204 eXtreme Low Power (XLP) device with 128 KB Flash and a rich set of peripherals to evaluate the PIC24F family.

No additional hardware is required and it comes with integrated demo code.

### Key Features:

- Features PIC24FJ128GA204 low power (XLP) MCU with an integrated Cryptographic engine
- Integrated programmer/debugger with USB interface
- Analog potentiometer, multiple user LED's, RGB LED and switches
- Full compatibility with MPLAB® Xpress, MPLAB X IDE, XC16 compiler and MPLAB Code Configurator
- Functionality expansion support with mikroBUS™ interface for Click™ Boards
- Wireless connectivity provision with Microchip's BM71 Bluetooth LE module footprint

**Order Your PIC24F Curiosity Development Board Today at:**

**www.microchipdirect.com**

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# EPE product review

# LabNation SmartScope

AUX
LabNation
A
B

### by Mike Tooley

***In a world of screens – from smartphones and tablets to laptops and desktop PCs – is the traditional oscilloscope a good buy, or should we move over to a new, more compact technology? Mike Tooley puts LabNation's Kickstarter-funded SmartScope to the test.***

## LabNation SmartScope

If you are enthusiastic about electronics above a superficial level, you will – sooner or later – need a way of displaying time-related waveforms of the signals and voltages in your circuits. To do this you will need some form of oscilloscope. Depending on the depth of your pockets, you can purchase such an instrument from as little as £300 to as much as £5000, or more. Furthermore, the choice of instrument can be bewildering due to the huge variation in features, displays, controls and specifications offered.

My own workshop sports a variety of different types of oscilloscope, including two elderly analogue 'scopes used mainly for RF work, a digital storage oscilloscope (DSO) used for low frequency and digital work, and an external high-speed ADC module that works in conjunction with an ancient desktop computer for recording waveforms. Naturally, all this kit consumes quite a lot of precious space and absolutely none of it is portable. The big question is, could all this kit be replaced by a single low-cost device? The surprising answer seems to be 'yes' – all you need is a 'SmartScope'!

Table 1: Extracts from the quoted SmartScope specification

| Feature | Specification | Notes |
|---|---|---|
| Channels | 2 | |
| Bandwidth (each ch.) | 30MHz | Measured at –3dB |
| Sample rate | 2 × 100MS/s | |
| Pre-trigger | 16 × full-scale (max.) | |
| Post-trigger | Full-scale (max.) | |
| Input voltage range | ±35V (max.) | ±300V (max.) with ×10 probes |
| Voltage scale | 20mV/div (min), 10V/div (max) | |
| Max input voltage | 40V pk.-pk. | |
| Input coupling | AC or DC | Selectable |
| Resolution | 8-bit | Recorded waveforms can be stored in Matlab (.mat) or as .csv files through Dropbox. |
| Input impedance | 1MΩ parallel with 10pF | Standard BNC connectors, without probes attached |
| Data delay to host | Less than 10ms | |
| Sample depth | Up to 4 million samples per ch. | |
| Trigger | Internal or external | Selectable |

## Enter the SmartScope

SmartScope is a high-performance 30MHz digital storage 'scope that will fit in your pocket. The instrument is dual channel and offers a sampling rate of 2 × 100M samples per second Suitable for use in a wide range of operating system environments (currently including Windows, Linux, OSX, Android and iOS) SmartScope can display waveforms, frequency spectra, and a host of other useful information using nothing more than a smartphone, tablet, laptop or desktop computer.

SmartScope was funded through a Kickstarter campaign in which nearly 1500 backers made it possible to develop and manufacture the very first batch of 2500 SmartScopes. Since then, the project has gained further momentum and, thanks to an active community of supporters, the user-base has grown considerably.

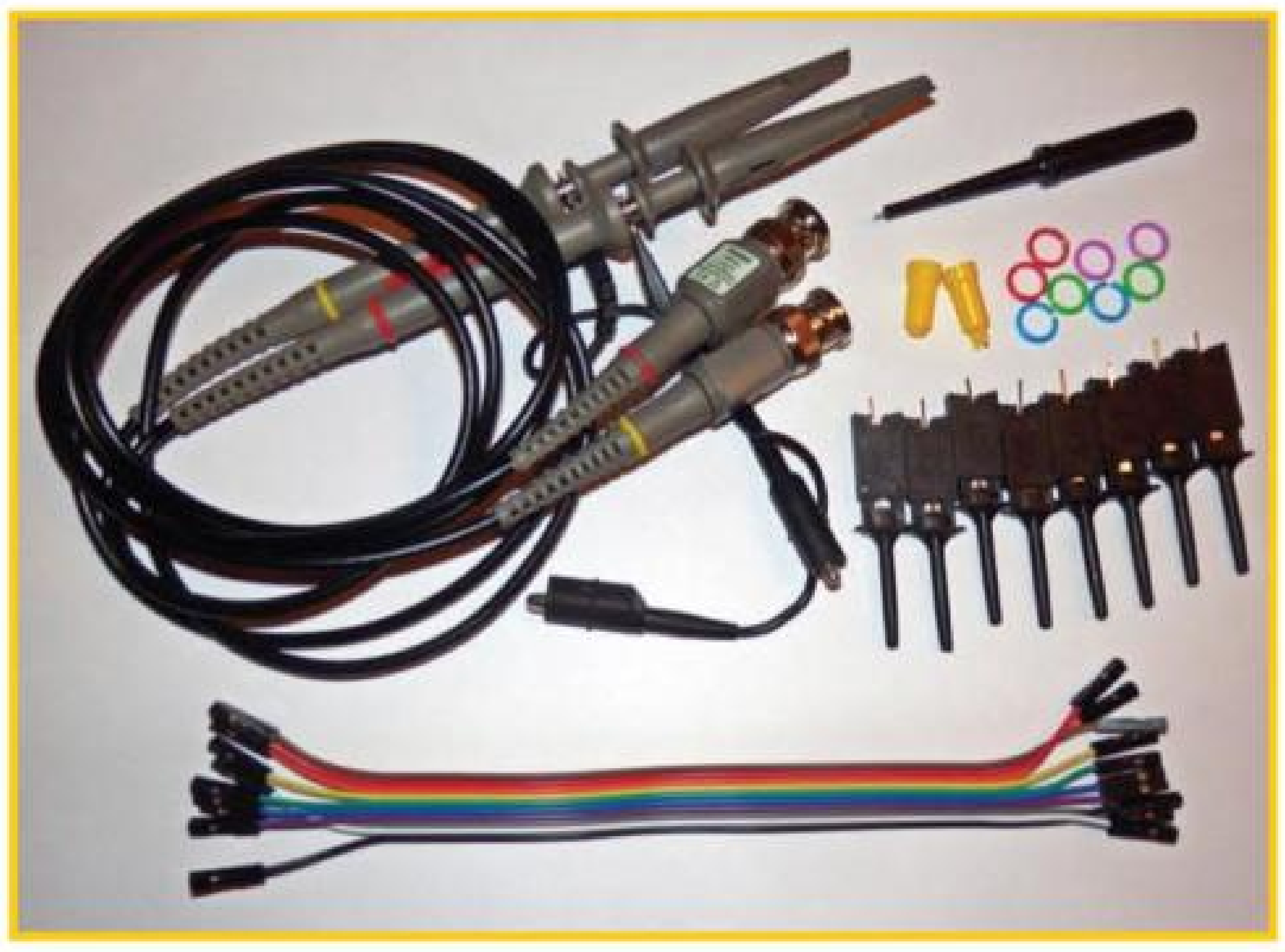
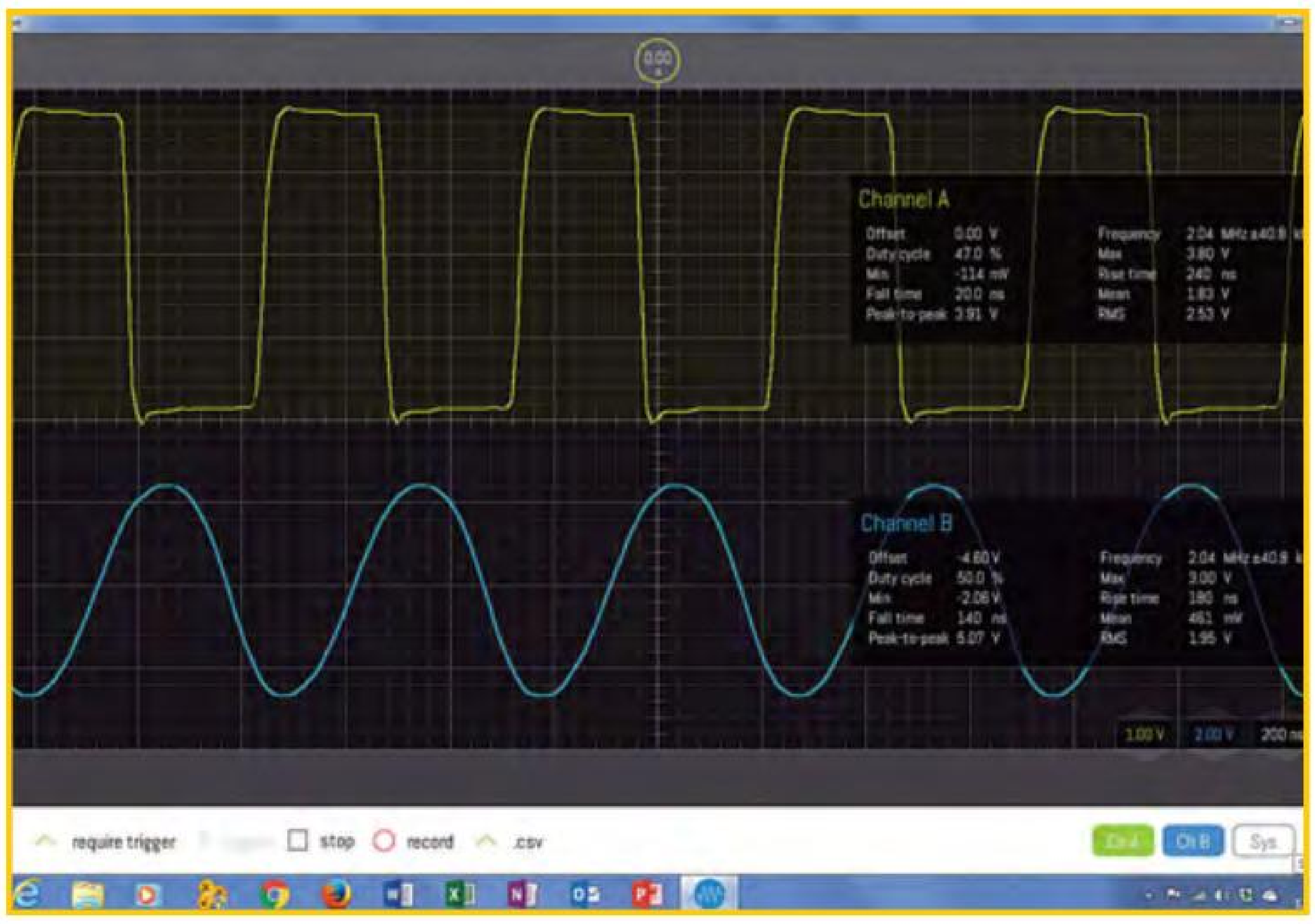


*Fig.1. SmartScope is supplied with a comprehensive set of accessories including two switchable ×1 and ×10 probes, a digital cable and grabbers.*



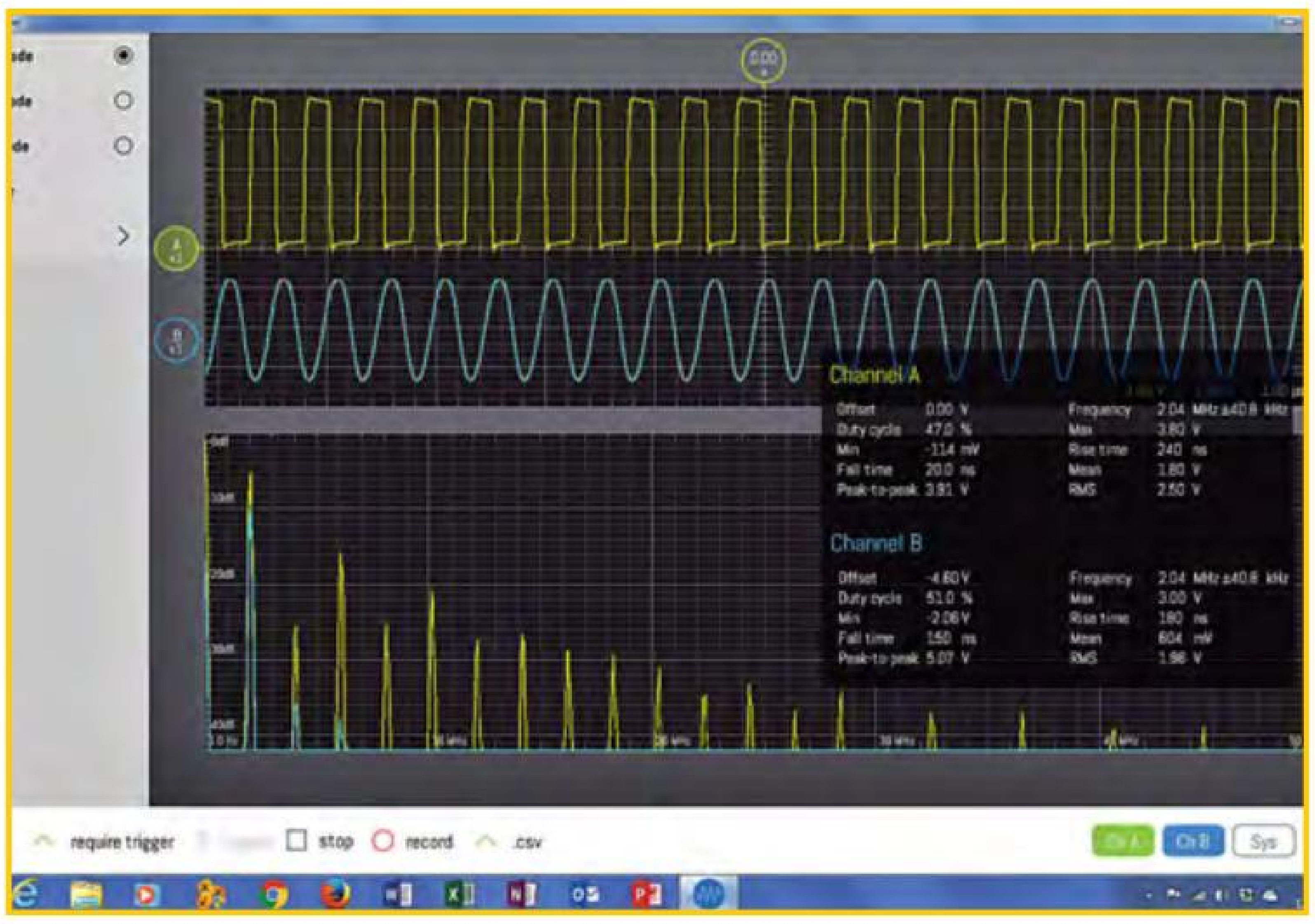
Channel A

Offset 0.00 V
Duty cycle 47.0 %
Min -114 mV
Fall time 20.0 ns
Peak-to-peak 3.91 V
Frequency 2.04 MHz ±40.8 k
Max 3.80 V
Rise time 240 ns
Mean 1.83 V
RMS 2.53 V

Channel B

Offset -4.60 V
Duty cycle 50.0 %
Min -2.06 V
Fall time 140 ns
Peak-to-peak 5.07 V
Frequency 2.04 MHz ±40.8 k
Max 3.00 V
Rise time 180 ns
Mean 461 mV
RMS 1.95 V

*Fig.2 2MHz square and sine waves under investigation.*



Channel A

Offset 0.00 V
Duty cycle 47.0 %
Min -114 mV
Fall time 20.0 ns
Peak-to-peak 3.91 V
Frequency 2.04 MHz ±40.8 kHz
Max 3.80 V
Rise time 240 ns
Mean 1.80 V
RMS 2.50 V

Channel B

Offset -4.60 V
Duty cycle 51.0 %
Min -2.06 V
Fall time 150 ns
Peak-to-peak 5.07 V
Frequency 2.04 MHz ±40.8 kHz
Max 3.00 V
Rise time 180 ns
Mean 604 mV
RMS 1.96 V

*Fig.3. Displaying frequency spectra of the waves in Fig.3.*

## What you get

The instrument is supplied in a sturdy laser-engraved aluminium enclosure (measuring a mere 11 × 6.4 × 2.4 cm) and is supplied with a comprehensive set of accessories including two good quality ×1 and ×10 compensated 'scope probes, a digital cable with 'grabbers', and a mini-B USB cable to connect the SmartScope to your PC, smartphone, tablet or laptop. The user manual is not supplied in printed form but can be accessed from LabNation's website.

## Specification

Despite its low cost, SmartScope has a comprehensive specification (Table 1). The measurement bandwidth (set by the 100Ms/s sampling rate and other considerations) is a respectable 30MHz. It is possible to display waveforms up to 50MHz (half the sampling rate) but amplitude and rise/fall time measurements will no longer be accurate. The vertical sensitivity (20mV/division) is adequate for most audio and small-signal applications. The 8-bit resolution of the SmartScope may at first appear rather low. However, the display is effectively smoothed by blending the ten most recent waveforms on top of one another. This goes a long way to explaining my initial surprise to find that the display was typical of a much higher resolution than the mere 8-bits quoted in the SmartScope specification.

## Operating modes

SmartScope can operate in several different display modes, including analogue, digital and mixed modes. Within each of these main modes, a number of secondary modes can be selected. For example, when the analogue mode is selected (similar to a conventional dual-beam 'scope) you can select X-Y mode, perform various operations on the signals, and also display a frequency spectrum of the waveform using fast Fourier transform (FFT) techniques.

The digital mode provides an 8-bit logic analyser and, once again, there's a variety of secondary modes that will, for example, allow you to decode UART/RS-232, I$^2$C or SPI data. In addition to these powerful features you can link SmartScope to your Dropbox account to store and retrieve waveform data from the cloud as well as from your host device.

## Accessories

SmartScope comes with a handy set of probes and accessories. The ×1 and ×10 settings on the probes result in measurement bandwidths of 6MHz and 30MHz respectively. The corresponding Y-scale resolution is 2mV/ADC unit and 20mV per ADC unit respectively. The probes are well made, fitted with compensated BNC connectors. The 10-way digital ribbon cable attaches a 16-way IDC connector accessible from the rear of unit. A set of grabbers can be attached to the ribbon cable and a USB cable is provided for connection to the host device.

## Software installation

I put SmartScope through its paces using a variety of different host systems, including an Android smartphone, an elderly Samsung tablet with a 10-inch screen, a recent Lenovo laptop, and a mid-range desktop PC operating under Windows 10. Setting up all four of these devices couldn't have been simpler. The required code downloaded quickly and seamlessly from the LabNation website and I was up and running in a matter of minutes.

## In use

Helpful 'How to' videos explain the basic SmartScope controls; eg, cursors, making measurements, and the acquisition modes. Further advice is available from the SmartScope Wiki.

The smartphone display was just about usable but, I found it was a little difficult to see fine detail on complex waveforms and to make precise adjustments using the small touch screen. By contrast, the tablet and laptop displays were consistently excellent, as was the desktop PC with mouse control. For preference, I would probably choose either a laptop or Android tablet since both platforms proved easy to use with the added advantage of being eminently portable.

The display is clear and is provided with two options, light and dark (I much

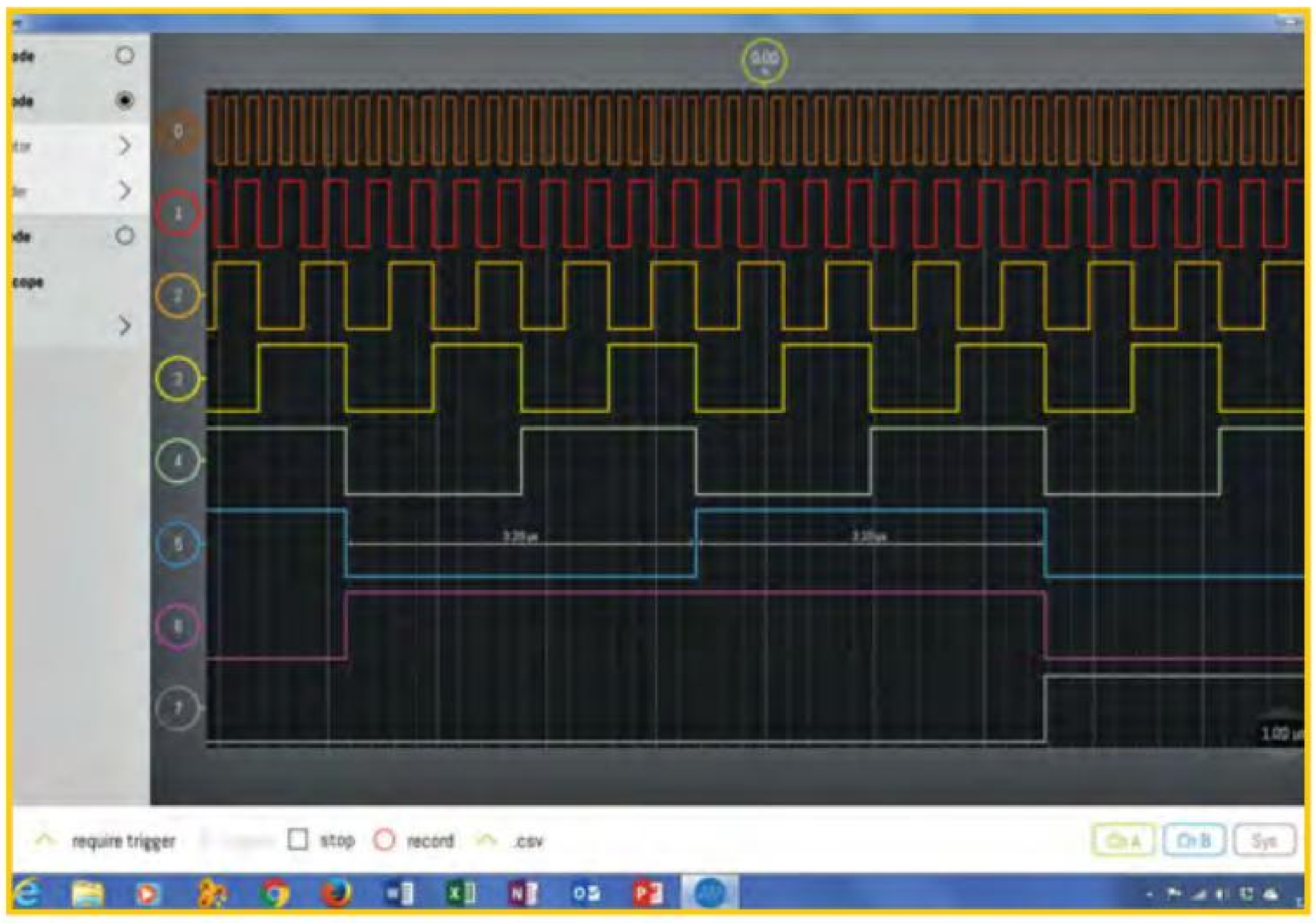


*Fig.4. 8-channel logic analyser display.*

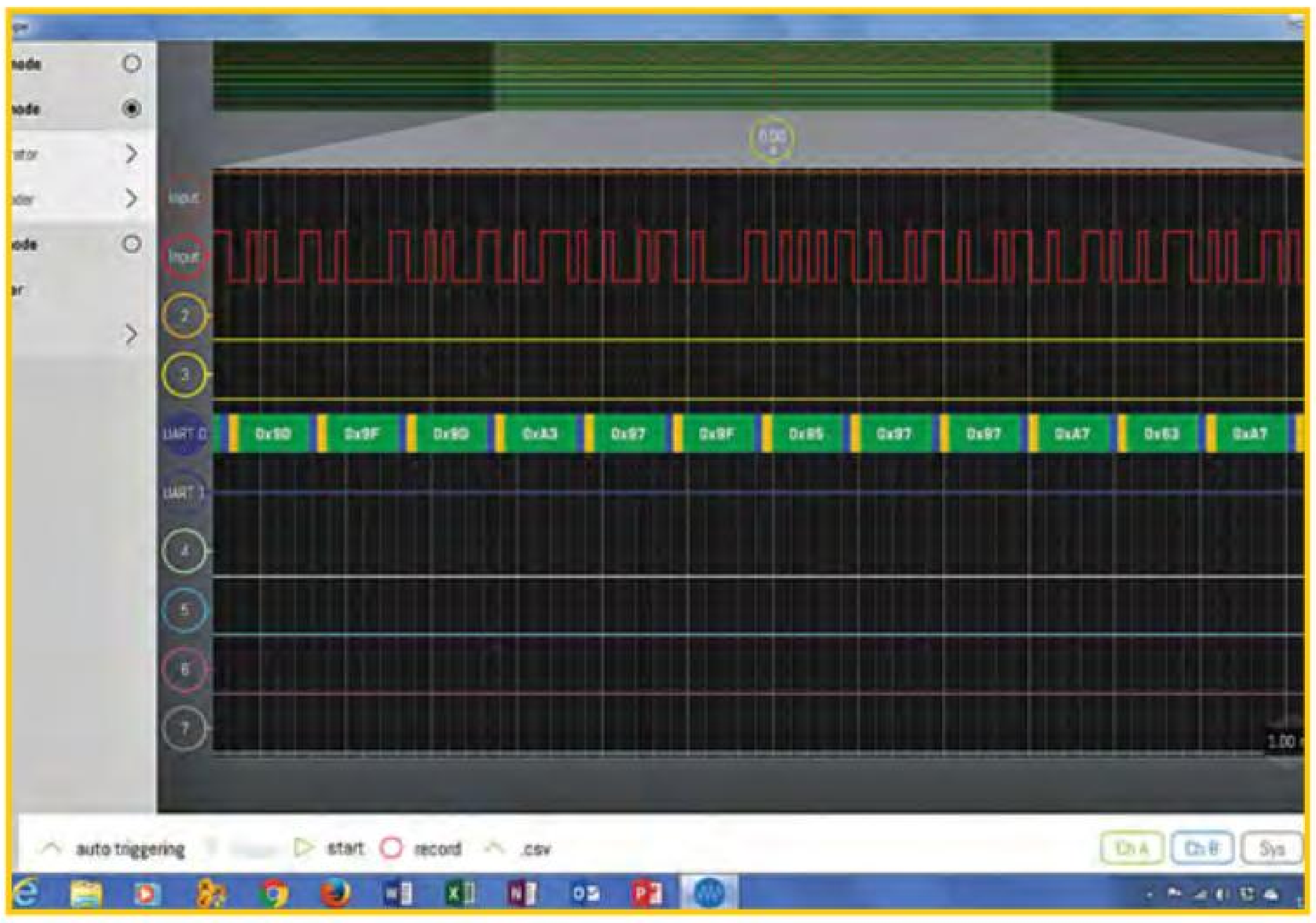


*Fig.5. Decoding RS-232 serial data from a GPS receiver.*

preferred the latter) and the system measurement box shows the length of the acquisition buffer as well as the sample rate. By default, the acquisition buffer is twice the size of the one you see on the grid. The viewport is moved around by simply dragging the highlighted part; all very simple and intuitive.

I checked SmartScope with a variety of everyday signals. Fig.2 shows the display obtained with a 2MHz TTL square wave applied to Channel A and a synthesised 2MHz sinewave applied to Channel B. By clicking on the Ch.A and Ch.B button at the bottom right of the display, additional information is made available within the two text panels superimposed on the display. Note how important waveform parameters are displayed, including frequency, duty cycle, rise and fall time. Fig.3 shows the same two waveforms but with an added display of their frequency spectra on a linear scale extending up to 50MHz.

### Logic analyser

The logic analyser capability of the SmartScope is shown in Fig.4. This shows the output of a binary divider. By clicking on a waveform of choice (in this case D5) the mark and space times appear superimposed on the waveform. This is an extremely useful feature and removes the need to use the grid markings to measure time intervals. Finally, Fig.5 shows how the built-in protocol decoder feature can be used to decode RS-232 serial data from a low-cost GPS module with its output connected to digital input, D1.

### Triggering

Triggering is a crucial feature in any oscilloscope and can often make a considerable difference to usability. Happily, the SmartScope trigger controls are both effective and intuitive. If you are used to setting up a conventional oscilloscope you will have little problem with them and the trigger point can be very conveniently selected using a cursor on the vertical axis (placing this outside a signal's voltage range will effectively disable triggering).

Triggering is on rising and/or falling edges, and you can cross-trigger an analogue signal from digital data and vice versa. In addition, LabNation is planning to incorporate a pattern-triggering feature. There's also an external trigger input via the instrument's AUX connector, allowing you to set the trigger voltage to any level in the range 0V and +3.3V.

### Protocol decoders

When examining digital signals, a useful feature of the SmartScope is the ability to decode signals that use common communication protocols, such as UART/RS-232, I$^2$C and SPI. You can easily select the part of a waveform that you wish to decode and then select the protocol that is being used. The SmartScope display will then show you the data in various formats, including binary and hexadecimal. If you interface serial devices to microcontrollers this is invaluable. Plus, if you need to decode an unusual protocol it is possible to develop and add your own protocol decoder to those already available.

### Waveform generation

A valuable bonus of the SmartScope is its integral arbitrary waveform generator (AWG). This has single-channel analogue capability as well as four digital channels. The analogue signal output level is in the range 0 to 3.3V with a maximum slew rate of 30ns/V and a step size of 13mV. Standard waveforms are provided (sine, square, triangle...) but the instrument will also allow you to construct an arbitrary waveform defined using a comma-separated variable (.csv) file, which can be produced in virtually any spreadsheet. In addition, the four digital waveform channels operate with a sample rate of up to 100MS/s with selectable output levels of 3.3V or 5V. This makes the unit ideal for use with virtually all current types of microcontroller (eg, Raspberry Pi or Arduino). A nice feature is that the digital waveform outputs are diode protected against inadvertent polarity reversal.

### Upgrading

Future upgrades of the resident firmware should be relatively easy since the field-programmable gate array (FPGA) firmware is flashable through the USB controller (as is the firmware of the USB controller itself). Both operations can be performed without further manual intervention and without opening the SmartScope enclosure.

### Open source

LabNation has left some parts of the SmartScope project 'open' so that you can develop your own applications or modify those that have been created by others. So, if you want to build your own 'scope interface or change what runs inside the FPGA, the schematics, sample source and help from others on the Forum will undoubtedly help. The open-source code is available on Github and the design files are available on the Wiki. Plus, there's on-going product development by LabNation, with Beta versions of the latest software available.

### Demonstration features

The SmartScope software can be freely downloaded without the need to purchase the SmartScope hardware. The instrument's 'dummy mode' will give you a 'feel' for using the software, but an even better option would be to test the application on an Android platform. Here, the dummy mode has been made more interactive by allowing you to test the device in 'real oscilloscope' mode based on audio rather than USB input. Note, however, that the sampling rate will only be 44kHz and the software will only provide meaningful measurements over the audio frequency range.

### Q&A with LabNation

Last, but not least, I spoke to Bruno Buyssens at LabNation to get a few more details on purchase and the way ahead for SmartScope.

*What's next for SmartScope?*
We keep on improving the features and functionality of the SmartScope. Each software update contains new firmware, so we really enhance the hardware itself. In parallel, we're working on a much more high-performance version of the hardware. The goals we've set for this next version are quite high, which means it's not easy to predict when it is going to hit the market.

*How do readers place an order?*
Readers can buys the Smartscope at: **www.lab-nation.com/store**. We accept PayPal and credit card payments. If this is not possible, then send an email to **info@lab-nation.com** and we will find a way.

*Tablets cost as little as £30 – time for a SmartScope with integral display?*
Our distributors have suggested this as an easy extension of our product range. However, the cost of tablets with *decent* performance still approaches the cost of SmartScope, and since the whole point of SmartScope is to re-use what you have already (a performance tablet/phone), we're not sure this would be a success.

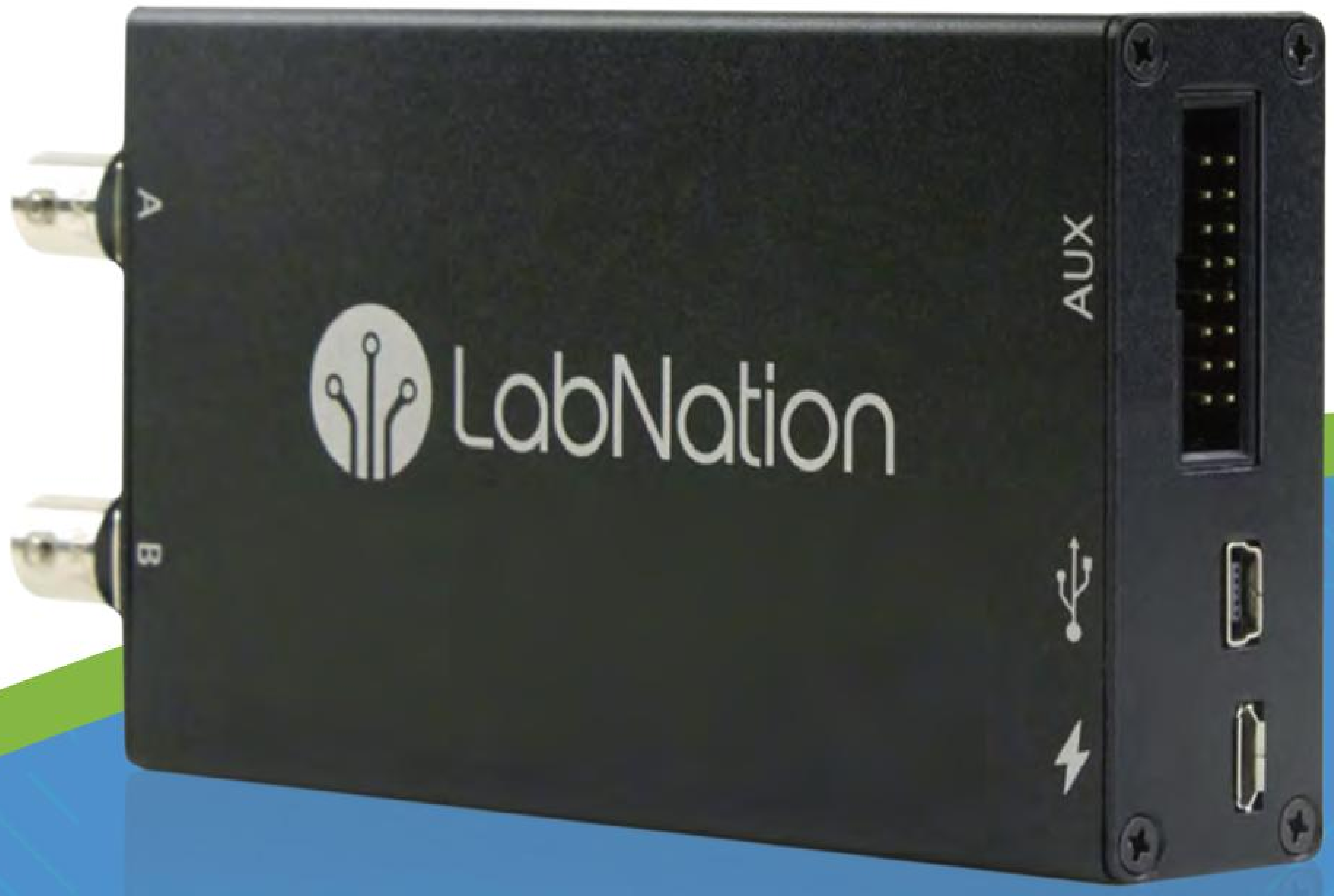
*How are users divided across different operating systems?*
It's hard to tell; I can quote the breakdown of software downloads from our site:
Win: 32%
Android: 27% Lin: 17%
MacOS: 16% iOS: 8%
However, the vast majority of Android and Linux installations are installed from other repositories (like the Play store), so the percentages of these systems will be larger in reality. iOS is the smallest share because of the jailbreak requirement. We're working on a network bridge that is going into beta next week, which allows the SmartScope app to be installed from the regular AppStore.

### In conclusion

What would I change? Very little, the only very minor criticism is the absence of an LED indicator showing that USB power is being supplied to the unit. Without that there's just no indication that the unit is 'live'. The USB status indication at the bottom right-hand bottom corner of the display only shows that the device has been recognised (if the icon appears in green the device has been connected and has been recognised).

Priced at under 230 euros for a 100MS/s oscilloscope with 1M sample buffer, two switchable (×1 and ×10) compensated probes, a digital probe cable, and other accessories, the package is great value. Is SmartScope really a 'game changer'? The answer must be a definite 'yes'. LabNation have come up with an extremely useful and eminently portable instrument supported by some powerful and intuitive software. Equally at home in both the analogue and digital worlds, the SmartScope can be recommended without reservation.

LabNation


A
B
LabNation
AUX

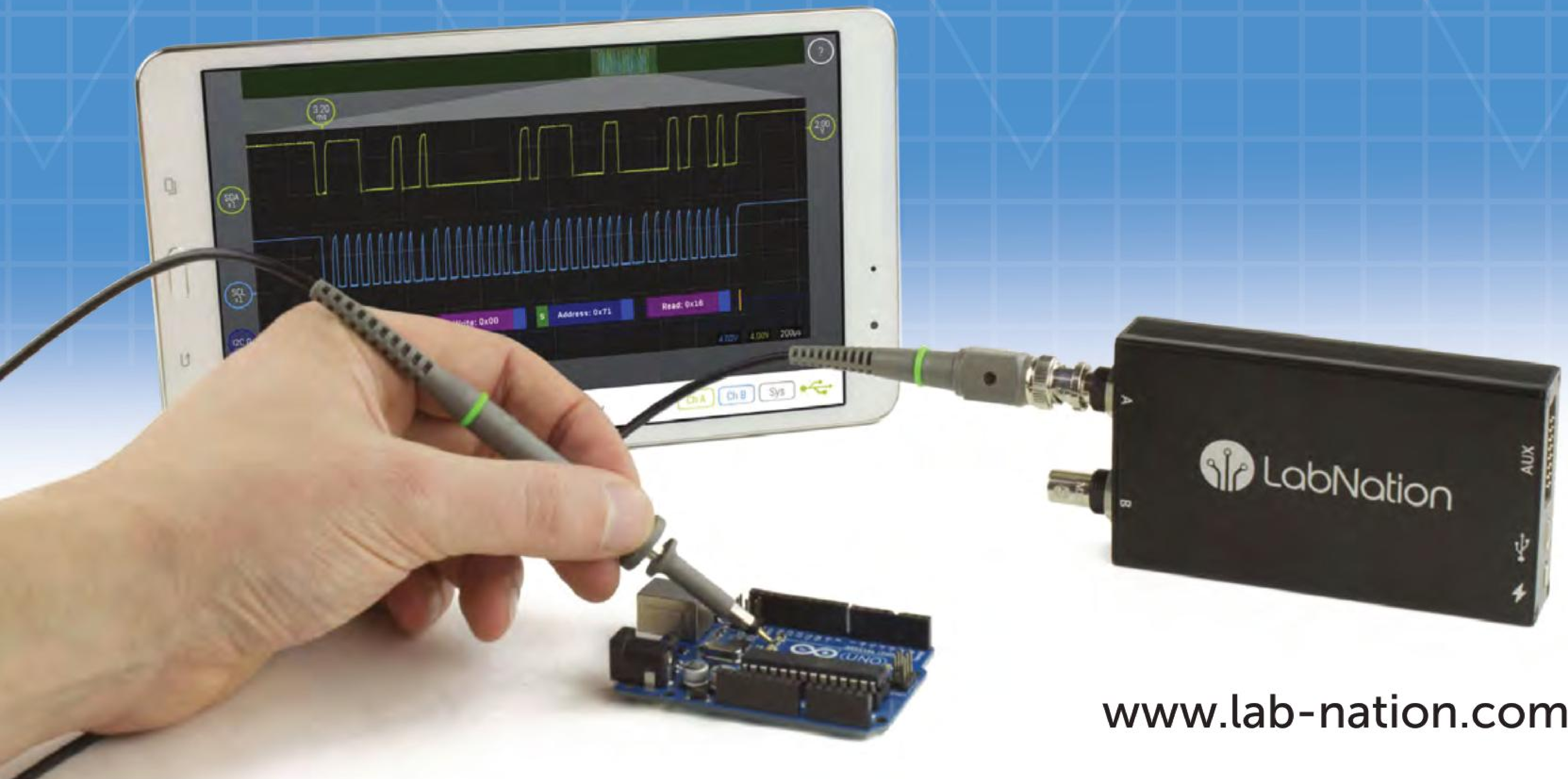
SmartScope

Compatible with laptop, tablet & smartphone

100% mobile with single wire connectivity

Intuitive touch interface

Benchtop performance in your pocket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HP 34401A Digital
Multimeter 6 ½ Digit

HP 54600B Oscilloscope Analogue/Digital
Dual Trace 100MHZ

MARCONI 2955B Radio
Communications Test Set

FLUKE/PHILIPS PM3092 Oscilloscope
2+2 Channel 200MHZ Delay TB, Autoset etc

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|---|---|---|
| LAMBDA GENESYS | PSU GEN100-15 100V 15A Boxed As New | £325 |
| LAMBDA GENESYS | PSU GEN50-30 50V 30A | £325 |
| HP34401A | Digital Multimeter 6.5 digit | £275-£325 |
| HP33120A | Function Generator 100 microHZ-15MHZ | £260-£300 |
| HP53131A | Universal Counter 3GHZ Boxed unused | £500 |
| HP53131A | Universal Counter 225MHZ | £350 |
| HP54600B | Digital Oscilloscope 100MHZ 20MS/S | from £75 |
| IFR 2025 | Signal Generator 9kHz - 2.51GHZ Opt 04/11 | £900 |
| Marconi 2955B | Radio Communications Test Set | £800 |
| R&S APN62 | Syn Function Generator 1HZ-260KHZ | £195 |
| Fluke/Philips PM3092 | Oscilloscope 2+2 Channel 200MHZ Delay etc | £250 |
| HP3325A | Synthesised Function Generator | £195 |
| HP3561A | Dynamic Signal Analyser | £650 |
| HP6032A | PSU 0-60V 0-50A 1000W | £750 |
| HP6622A | PSU 0-20V 4A Twice or 0-50V 2A Twice | £350 |
| HP6624A | PSU 4 Outputs | £350 |
| HP6632B | PSU 0-20V 0-5A | £195 |
| HP6644A | PSU 0-60V 3.5A | £400 |
| HP6654A | PSU 0-60V 0-9A | £500 |
| HP8341A | Synthesised Sweep Generator 10MHZ-20GHZ | £2,000 |
| HP83731A | Synthesised Signal Generator 1-20GHZ | £1,800 |
| HP8484A | Power Sensor 0.01-18GHZ 3nW-10uW | £75 |
| HP8560A | Spectrum Analyser Synthesised 50HZ - 2.9GHZ | £1,250 |
| HP8560E | Spectrum Analyser Synthesised 30HZ - 2.9GHZ | £1,750 |
| HP8563A | Spectrum Analyser Synthesised 9KHZ-22GHZ | £2,250 |
| HP8566B | Spectrum Analsyer 100HZ-22GHZ | £1,200 |
| HP8662A | RF Generator 10KHZ - 1280MHZ | £750 |
| Marconi 2022E | Synthesised AM/FM Signal Generator 10KHZ-1.01GHZ | £325 |
| Marconi 2024 | Synthesised Signal Generator 9KHZ-2.4GHZ | £800 |
| Marconi 2030 | Synthesised Signal Generator 10KHZ-1.35GHZ | £750 |
| Marconi 2305 | Modulation Meter | £250 |
| Marconi 2440 | Counter 20GHZ | £295 |
| Marconi 2945 | Communications Test Set Various Options | £2,500 |
| Marconi 2955 | Radio Communications Test Set | £595 |
| Marconi 2955A | Radio Communications Test Set | £725 |
| Marconi 6200 | Microwave Test Set | £1,500 |
| Marconi 6200A | Microwave Test Set 10MHZ-20GHZ | £1,950 |
| Marconi 6200B | Microwave Test Set | £2,300 |
| Marconi 6960B with | 6910 Power Meter | £295 |

| | | |
|---|---|---|
| Tektronix TDS3012 | Oscilloscope 2 Channel 100MHZ 1.25GS/S | £450 |
| Tektronix 2430A | Oscilloscope Dual Trace 150MHZ 100MS/S | £350 |
| Tektronix 2465B | Oscilloscope 4 Channel 400MHZ | £600 |
| Cirrus CL254 | Sound Level Meter with Calibrator | £40 |
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By Robert Penfold

# INTERFACE

## Analogue signal conditioning

**ALTHOUGH WE** live in a so-called 'digital world', the wider world is as analogue as it has ever been. So, it's often necessary to design digital circuits that are capable of dealing with analogue signals. In many cases this means using complex analogue-to-digital or digital-to-analogue converters, but something much simpler is all that is needed in some applications. The subject of frequency measurement has been considered in some recent *Interface* articles, and this is the type of application where digital electronics excels.

### Perfect logic

However, it only excels if the basic frequency meter design is fed with an input signal that switches quickly and cleanly between two appropriate logic levels. Depending on the signal level, raw analogue signals may be inadequate to drive the circuit, or there could be a risk of the input device being zapped by excessive voltages. Even if the voltage range is suitable, there is no guarantee that reliable results will be obtained. Analogue signals often vary at relatively slow rates and can contain a significant amount of noise. This can give spurious operations of the input device, either due to the noise, or a lack of stability in the circuit in the region of the transition voltage.

With a digital input signal there could obviously be problems if the logic levels of the input signal do not match those of the frequency meter circuit. Again, the input levels could be too low to produce any frequency count, or so high as to result in damage. A real-world digital frequency meter has to include signal conditioning that enables it to be used safely and reliably with a wide range of digital and analogue signals.

### Cleaning up

The simplest type of signal conditioner is a clipping amplifier. In other words, an amplifier that deliberately has its voltage gain set too high so that the output signal is clipped. A problem with this type of processing is that it will not necessarily work well with low input frequencies. By the standards of logic circuits, the transition from one logic level to the other could be relatively slow, and this method does not really address problems with noise on the input signal; in fact, it could easily make them worse.

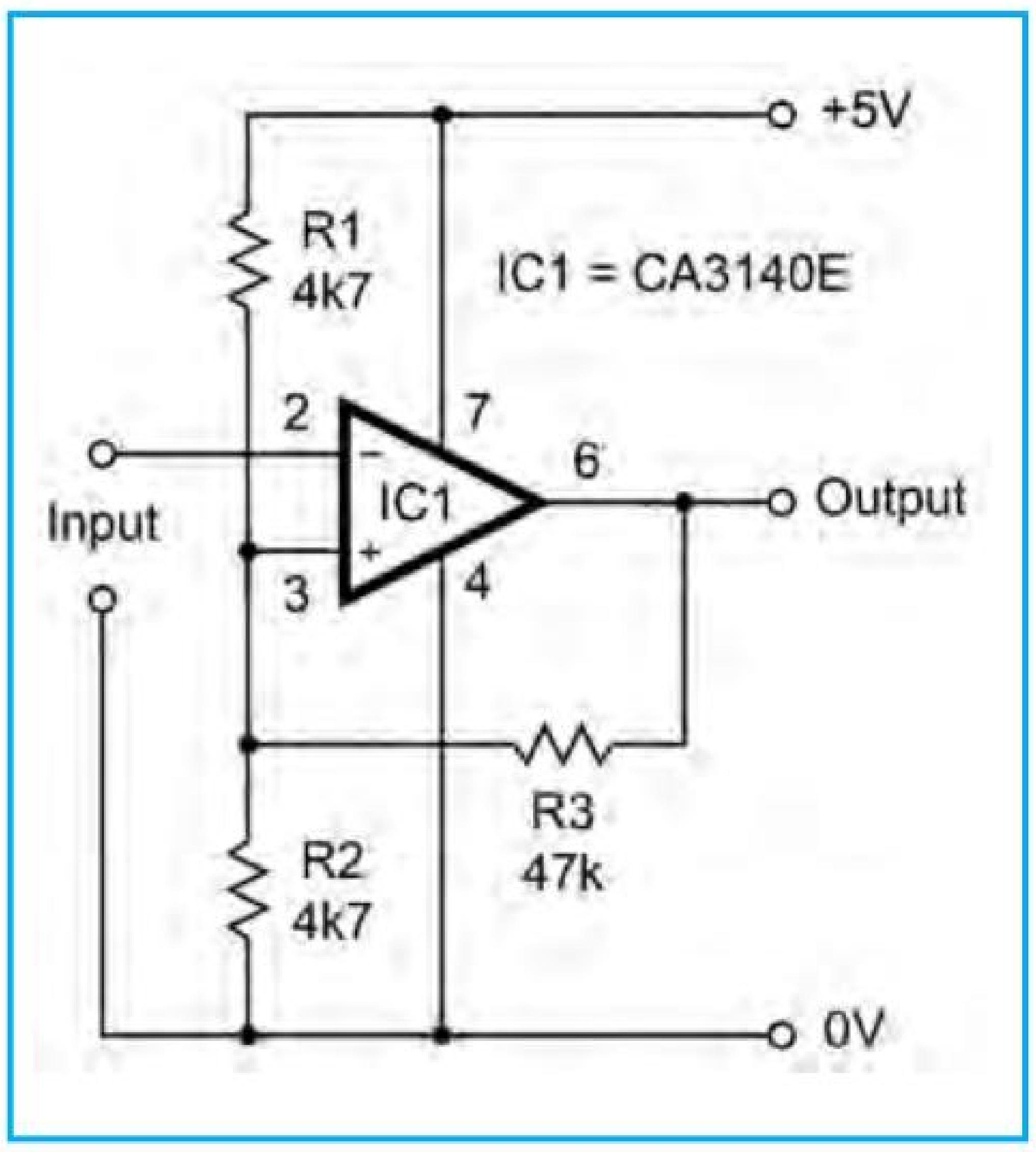

*Fig.1. Circuit for a basic Schmitt trigger based on an op amp. R3 provides positive feedback that provides the trigger action and introduces hysteresis*

The usual approach is to use some form of Schmitt trigger to make the conversion from an analogue signal to one at digital levels and speeds. A Schmitt trigger is a bit like a voltage comparator, where the output goes high if the input voltage goes above a certain threshold level, or low if the input goes below that level. In fact, an operational amplifier (op amp) used in the voltage-comparator mode is easily converted into a Schmitt trigger – see Fig.1.

In this version of a trigger circuit, an inversion is produced because the threshold voltage is set at the non-inverting (+) input, and the input signal is applied to the inverting (–) input. In the current context it does not matter if the signal is inverted, because whether or not it is inverted, its frequency is the same either way. R1 and R2 form a simple potential divider that sets the threshold voltage at half the supply potential, in other words, 2.5V. Normally, taking the input above this level would take the output low, but R3 provides positive feedback that modifies the behaviour of the circuit. With the output of IC1 high, R3 pulls the voltage at the non-inverting input higher than half supply voltage. The input therefore has to be taken above this increased threshold level before the output of IC1 starts to swing lower in voltage. As it does so, the feedback through R3 takes the threshold voltage lower, starting a regenerative action that results in the output rapidly going fully low. It does not matter how slowly the input voltage changes, or even if it becomes static once the threshold level has been reached. The regenerative action ensures that the output triggers to the low state once it has started to change.

With the output of IC1 in the low state, R3 now pulls the threshold voltage below half the supply potential. In order to switch the output back to the high state, the input signal therefore has to be taken well below half the supply potential. A regenerative action then triggers the output back to the high state, and reinstates the higher threshold level. This reluctance of the circuit to change state is called 'hysteresis', and the difference between the two threshold levels is termed the 'hysteresis voltage'. The transfer characteristic of a Schmitt trigger is something along the lines of that shown in Fig.2, with two instant and separate transition points. The logic symbol for a Schmitt trigger is the same as for an ordinary buffer, but with a simple representation of this transfer characteristic included inside the triangle.

Hysteresis ensures that a small amount of noise on the input signal does not cause multiple output pulses when a threshold level is reached. A large amount of noise immunity can be obtained by using a high hysteresis voltage, which in this example means using a relatively low value for R3. Care has to be taken though, since using too much feedback will result in the output *latching* at one or other of the output states. Most real-world trigger circuits have a hysteresis voltage of around 10 to 20 per cent of the supply potential. Incidentally, mechanical hysteresis is incorporated into the design of many on/off switches, where

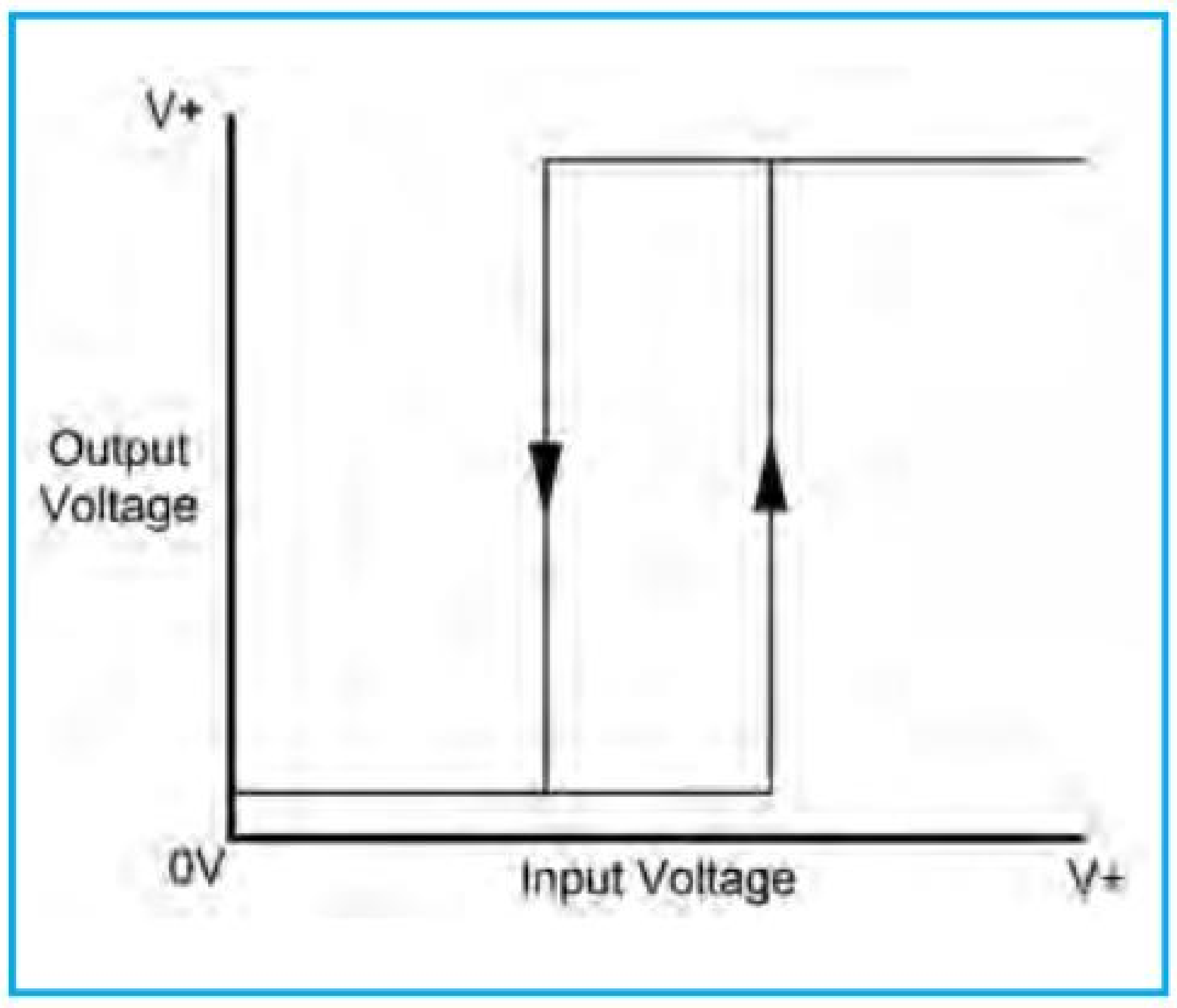

*Fig.2. Schmitt trigger transfer characteristic – it is used in circuit diagrams as part of the logic symbol for a Schmitt trigger*

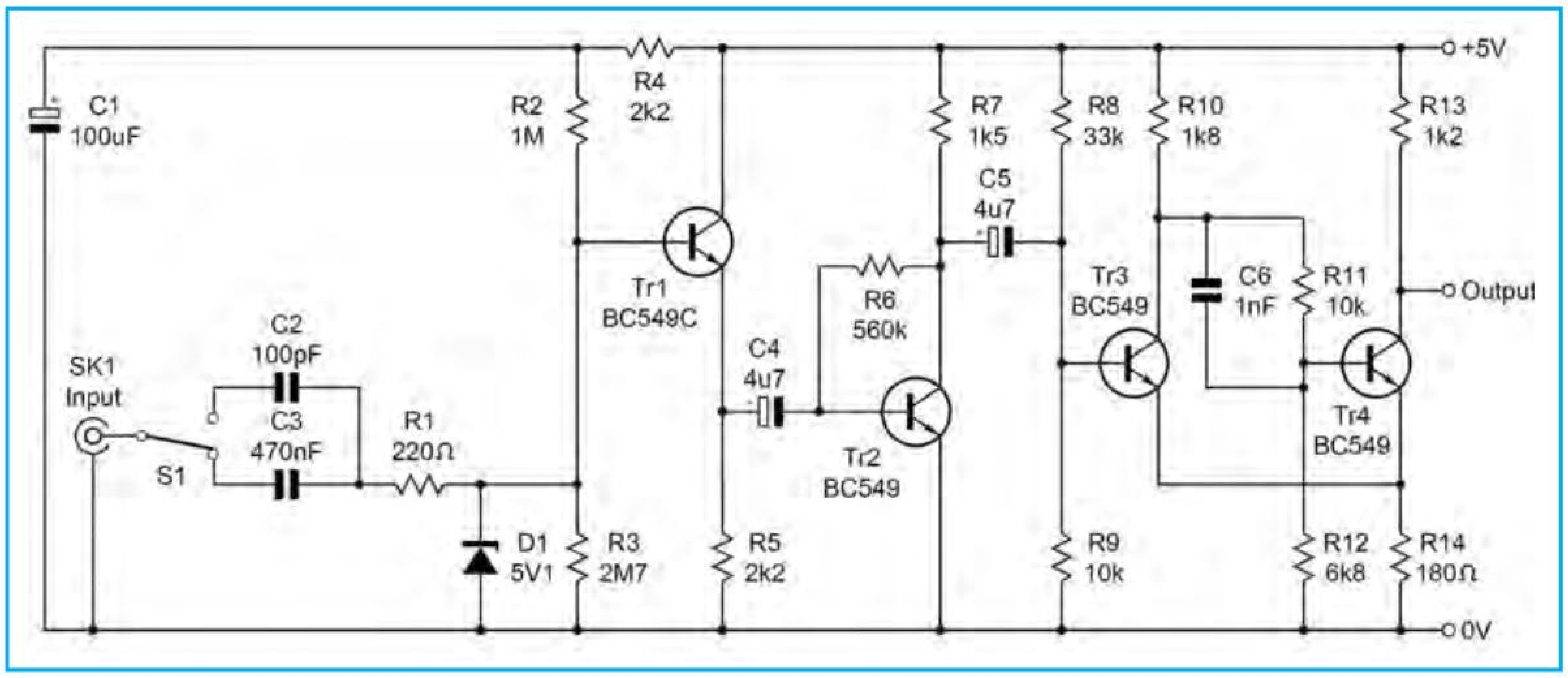

*Fig.3. Signal conditioning circuit that uses Tr1 and Tr2 as an input buffer stage and amplifier respectively. Tr3 and Tr4 are used in a conventional Schmitt trigger circuit*

it helps to minimise sparking at the contacts during transitions from one state to the other.

### High-frequency operation

Operational amplifiers are fine for Schmitt triggers that will operate at audio frequencies, and a little beyond, but they are not intended for use at higher frequencies. Also, they do not work at their best on low supply voltages, and most are not intended for single-supply operation. A discrete design is more suitable for operation in the megahertz region.

Fig.3 shows the circuit diagram for an input amplifier and Schmitt trigger based on four inexpensive transistors. S1 provides a choice of two input coupling capacitors (C2 and C3). It is C3 that is normally used, and its higher value gives a frequency response that goes beyond the lower end of the audio range. There can sometimes be problems with frequency measurement due to noise in the form of low-frequency 'hum' on the signal. This might genuinely be present on the signal source, or it could be mains hum picked up by the test leads. Either way, and despite the best efforts of the trigger circuit, it can produce erratic readings. Using C2 as the input capacitor gives a simple high-pass filter action that reduces hum and gives a better chance of obtaining stable readings.

Test equipment, such as a frequency meter often incorporates some form of over-voltage protection, and this is the purpose of R1 and zener diode D1. They form a simple clipping circuit that limits the maximum signal levels at about +5.1V and –0.7V. Ideally, R1 would have a high value so that there would be no risk of an excessive input current flowing, and to ensure that there would be minimal loading on the signal source if clipping occurred. In practice, its value has to be something of a compromise, because a high value would reduce the sensitivity of the circuit. The reduction would not be very great at low and middle frequencies, but R1 effectively forms a low-pass filter in conjunction with the capacitance of the circuit. This could result in the circuit becoming inoperative at high frequencies.

A simple two-stage amplifier circuit precedes the trigger circuit. Tr1 is used as an emitter-follower stage that gives the circuit a reasonably high input impedance of a few hundred kilohms. Minimal loading is therefore placed on the signal source, but the input impedance is inevitably much lower at high frequencies due to the input capacitance of the circuit. R4 and C1 filter any 'hum' or digital noise on the supply lines so that it is not coupled to the input of the amplifier via the biasing circuit. Tr2 operates as a common-emitter amplifier that significantly boosts the sensitivity of the circuit. An input level of more than about 10mV RMS will activate the trigger circuit, but the gain of Tr1, and therefore the sensitivity of the circuit as well, will fall away somewhat at high input frequencies.

Tr3 and Tr4 are used in a conventional Schmitt trigger configuration. The circuit is basically just two DC-coupled high-gain common-emitter stages. The regenerative action and hysteresis is obtained by having an emitter resistor (R14) that is shared by the two transistors. For instance, when Tr3 is switching off and Tr4 starts to switch on, there is an increase in the current through R14. This takes the two emitters more positive, which results in Tr3 being moved further towards switching off, and gives the required regenerative action.

### Higher achiever

This circuit works well up to a few megahertz and is adequate for many applications. When tried with a cheap (£3.80) 50MHz crystal tester and frequency meter kit from China, it was clearly the limiting factor though. The kit offers the usual China/eBay value for money, but has a major shortcoming. It works well as a frequency meter, but the input terminal goes direct to a pin of the PIC processor. It is unusable as a general-purpose digital frequency meter without the addition of a signal-conditioning circuit.

To improve high-frequency performance, I tried a circuit based on a 74HC14 hex inverting Schmitt trigger. Pinout details for a 14-pin DIL version of this chip (the 74HC14N) are provided in Fig.4, and Fig.5 shows the modified signal conditioning circuit. Only one of the six trigger circuits is needed in this application, but the five unused inputs of IC1 are connected to one or other of the supply rails in order to prevent spurious operation and possible damage to the device. The 74HC14 is a CMOS device, and as such it requires the usual anti-static handling precautions. The input amplifier is much the same as before, but Tr2 is run at a higher collector current in an attempt to improve the high-frequency performance, albeit at the expense of low-frequency gain. It worked well into the 20-30MHz region, which is all I required. Using specialist UHF transistors instead of the cheap general-purpose types specified here could probably boost high-frequency performance further.

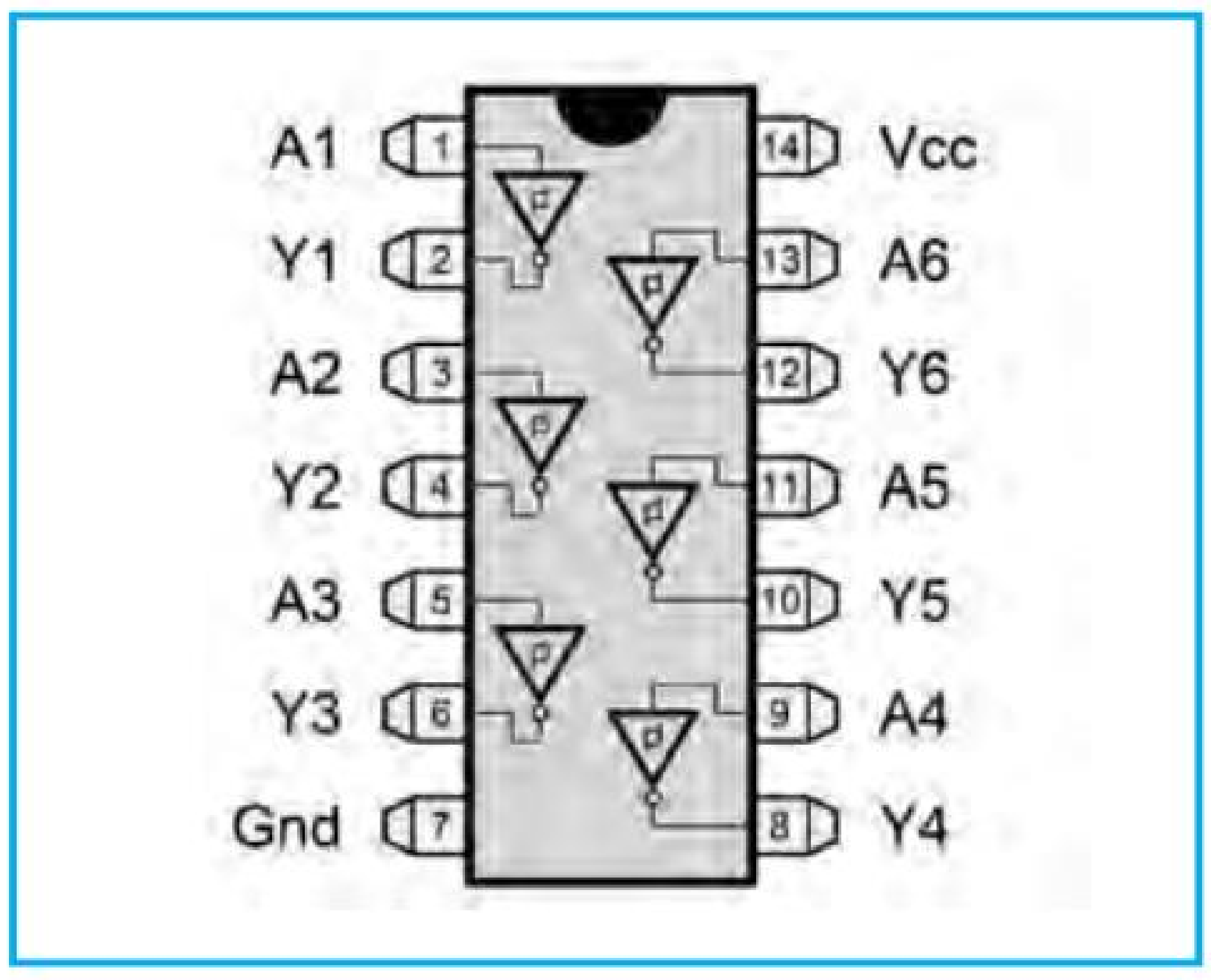

*Fig.4. Pinout details for the 14-pin DIL version of a 74HC14 hex inverting Schmitt trigger IC*

### Debouncing

Schmitt triggers are also useful for so-called switch 'debouncing'. Many digital circuits use pushbutton switches to input information of some kind. The problem with pushbutton switches, and mechanical switches in general come to that, is that they do not provide a 'clean' switching action. Spurious pulses tend to be produced at the moment they open or close. In some applications, such as a reset switch, this can be of no consequence. In others it could render the circuit virtually unusable. For example, when cycling through options in a menu system or something of that ilk, the switch would more or less pick an option at random.

Monostable and Schmitt trigger circuits are the normal choices for switch debouncing. A monostable is especially useful where a short pulse

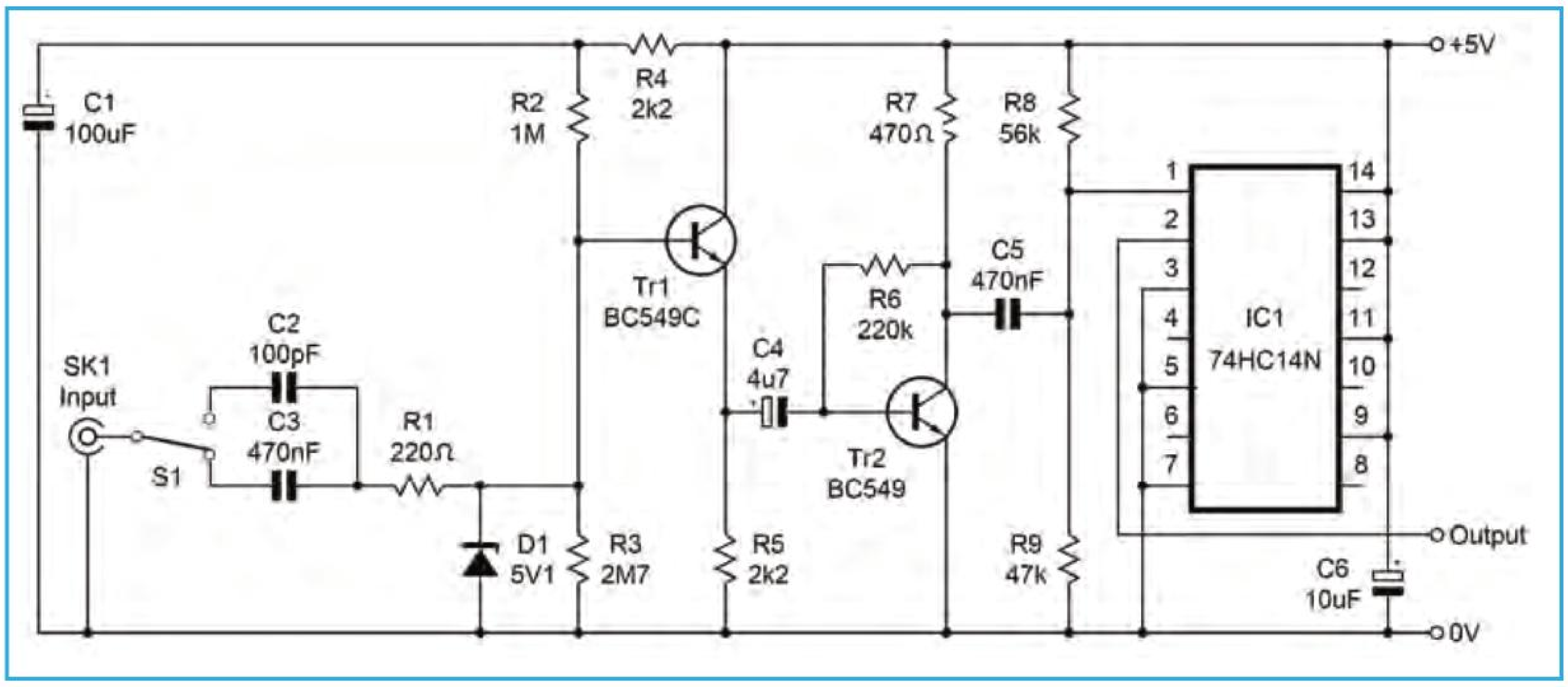

*Fig.5. This version of the signal conditioning circuit has slightly lower sensitivity, but a much improved high-frequency response*

must be generated each time a switch is operated, but either type can be used for straightforward 'cleaning' of the signal from a pushbutton circuit. The hysteresis of a Schmitt trigger is not sufficient to reliable remove noise from a pushbutton circuit, and it is normally accompanied by some simple filtering, as in the two circuits of Fig.6.

In Fig.6(a), C1 smooths any voltage spikes caused by contact bounce when the switch is pressed. R1 limits the peak current that flows through S1 as the contacts close, and C1 is rapidly discharged. This helps to minimise sparking and improve the contact life of the switch. Connecting a capacitor directly across the input of a CMOS logic device is a bit risky, and protection resistor R3 has therefore been included at the input of IC1. Due to the inversion through the Schmitt trigger, the output of the circuit goes high while the pushbutton switch is pressed. The circuit of Fig.6 (b) operates in essentially the same fashion as the one of Fig.6 (a), but the output is normally high and goes low when S1 is operated.

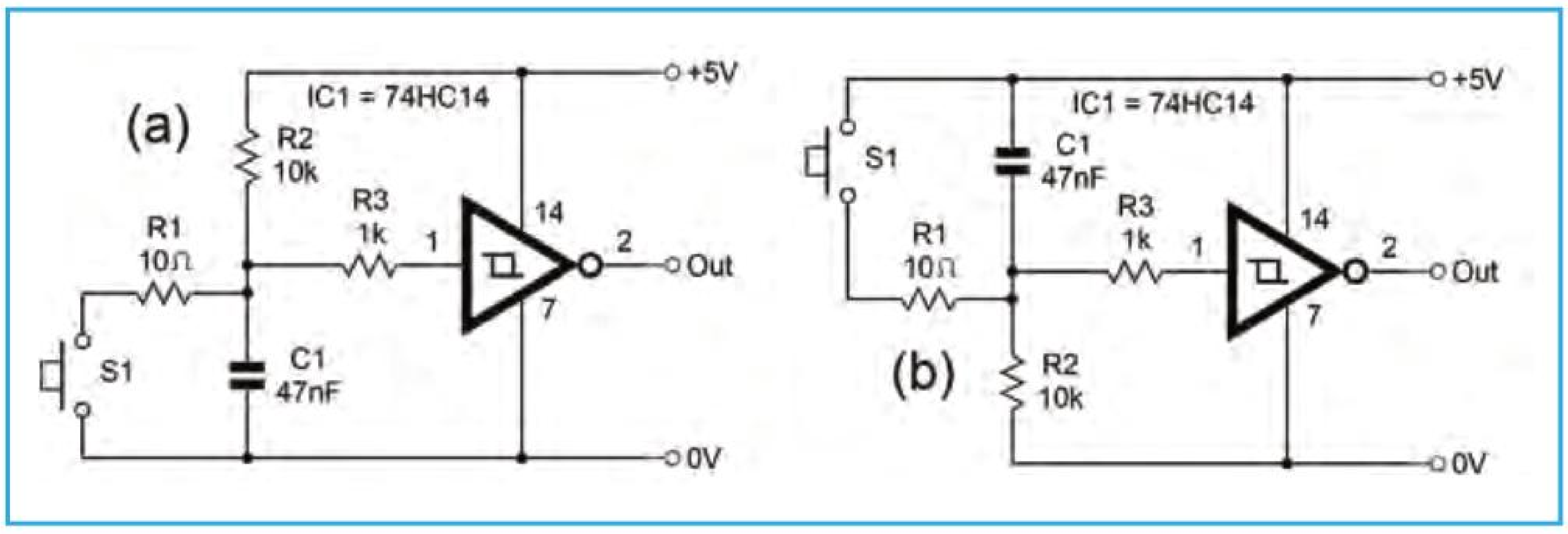

*Fig.6. Using a smoothing capacitor and a Schmitt trigger to provide switch debouncing. The output of (a) is normally low and goes high when S1 is pressed, while the circuit of (b) provides the opposite polarity response*

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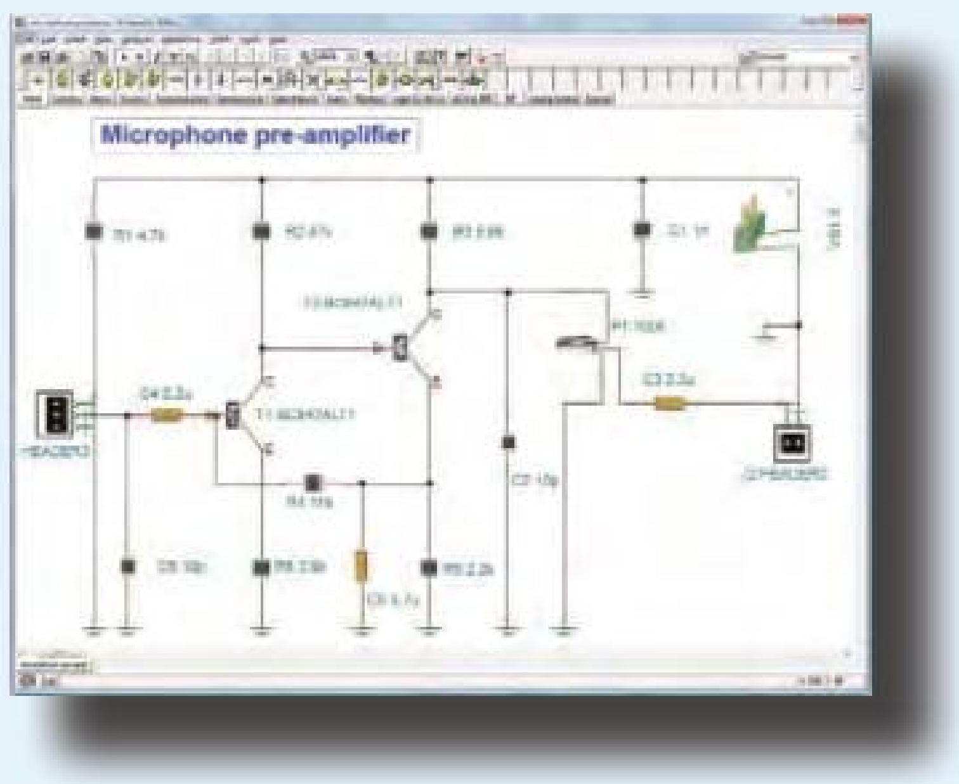

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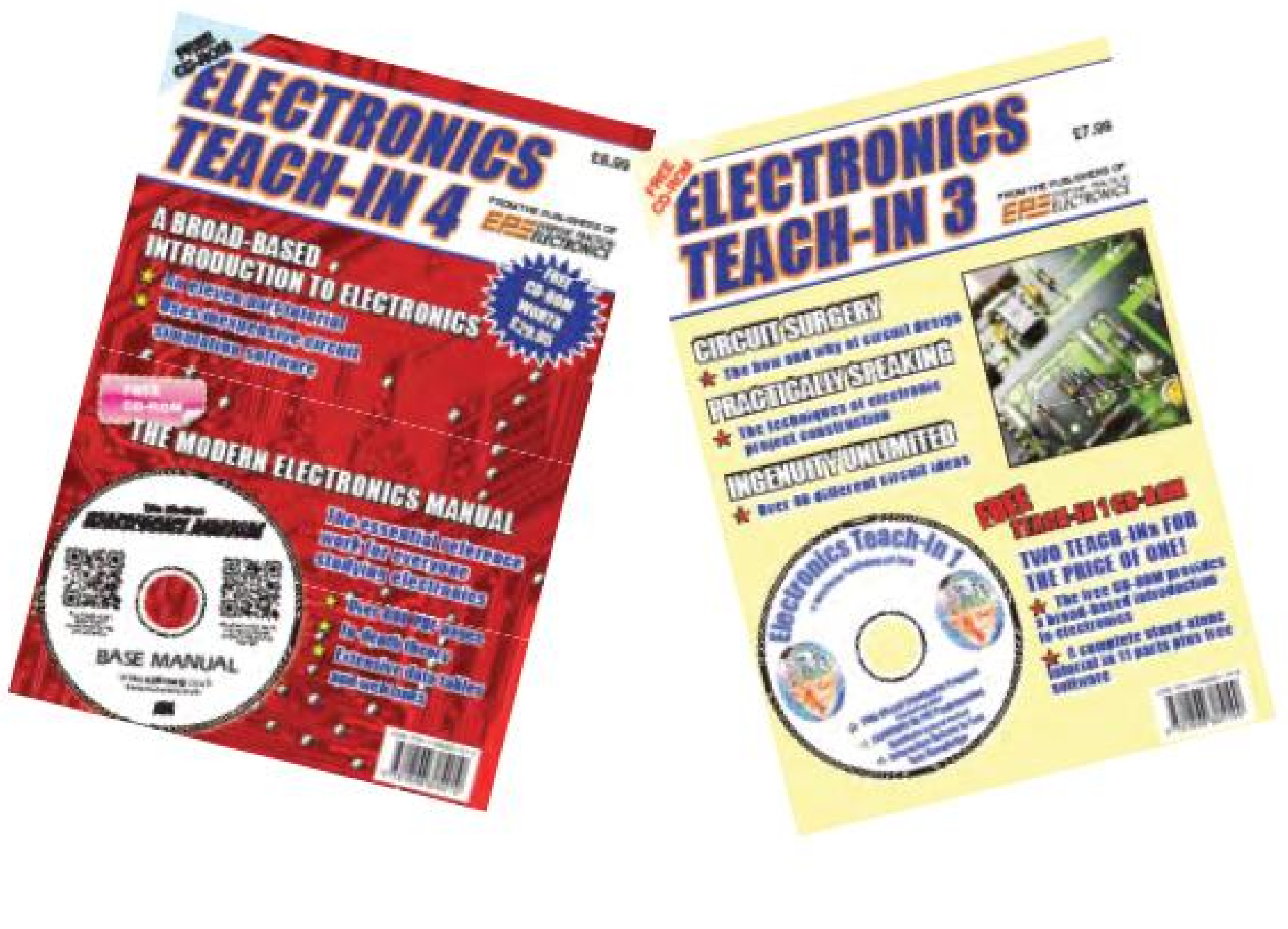

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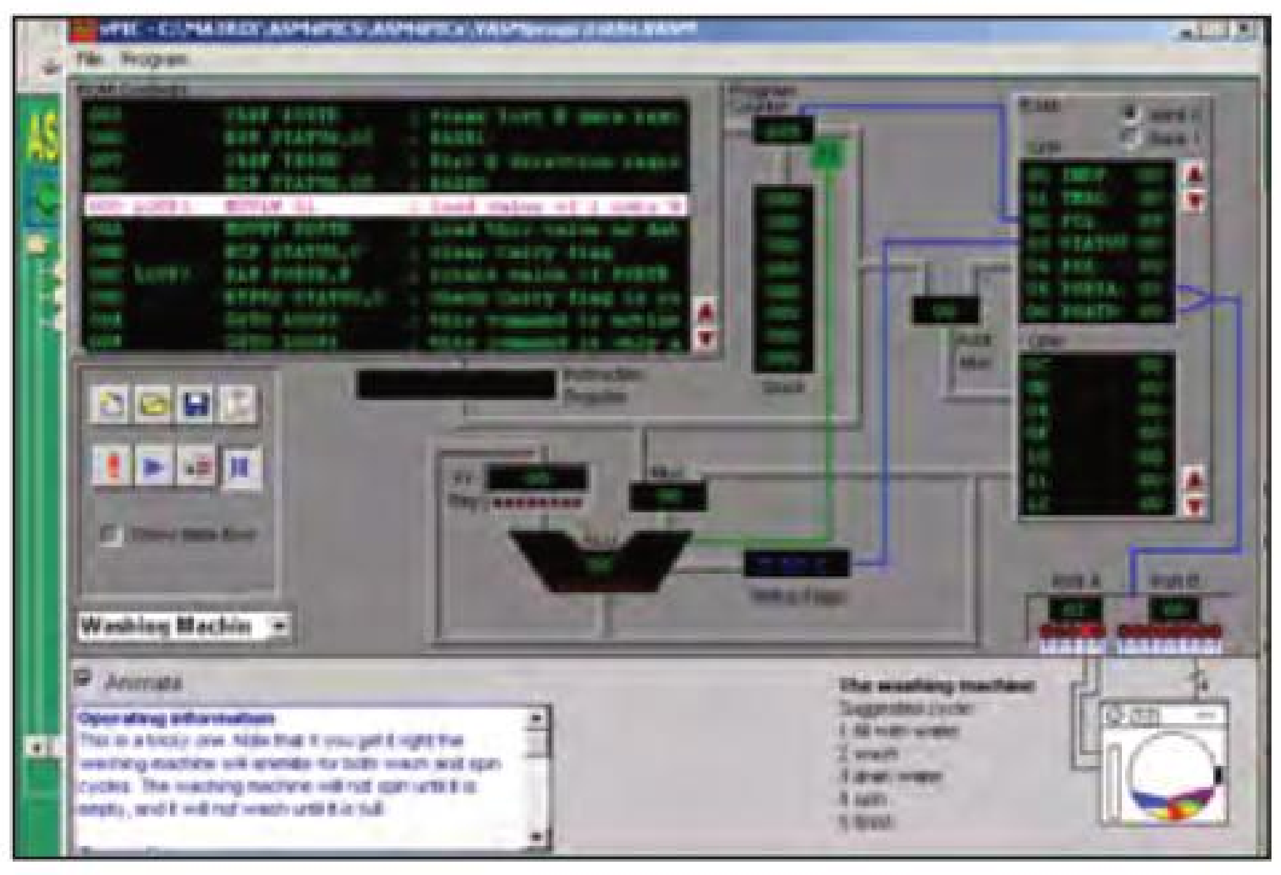

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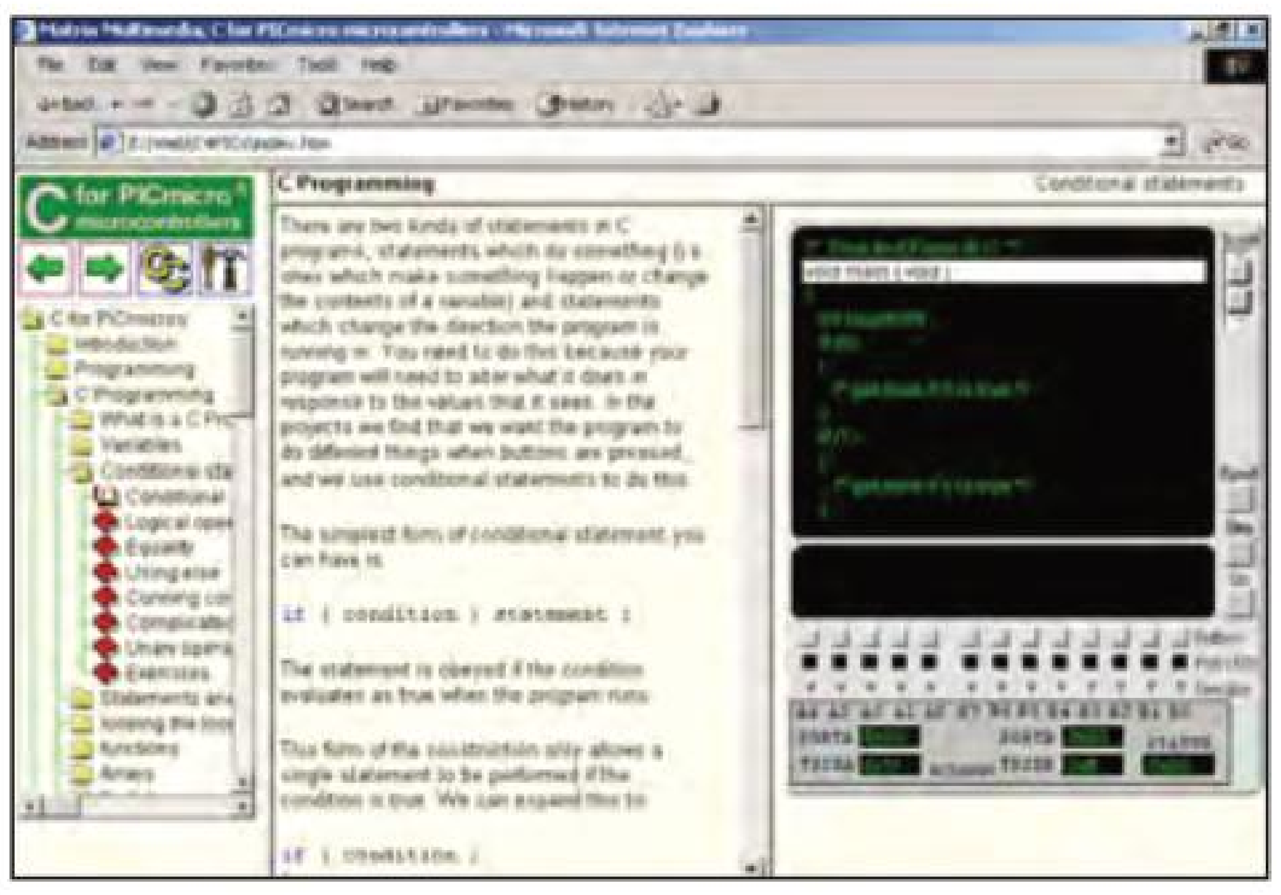

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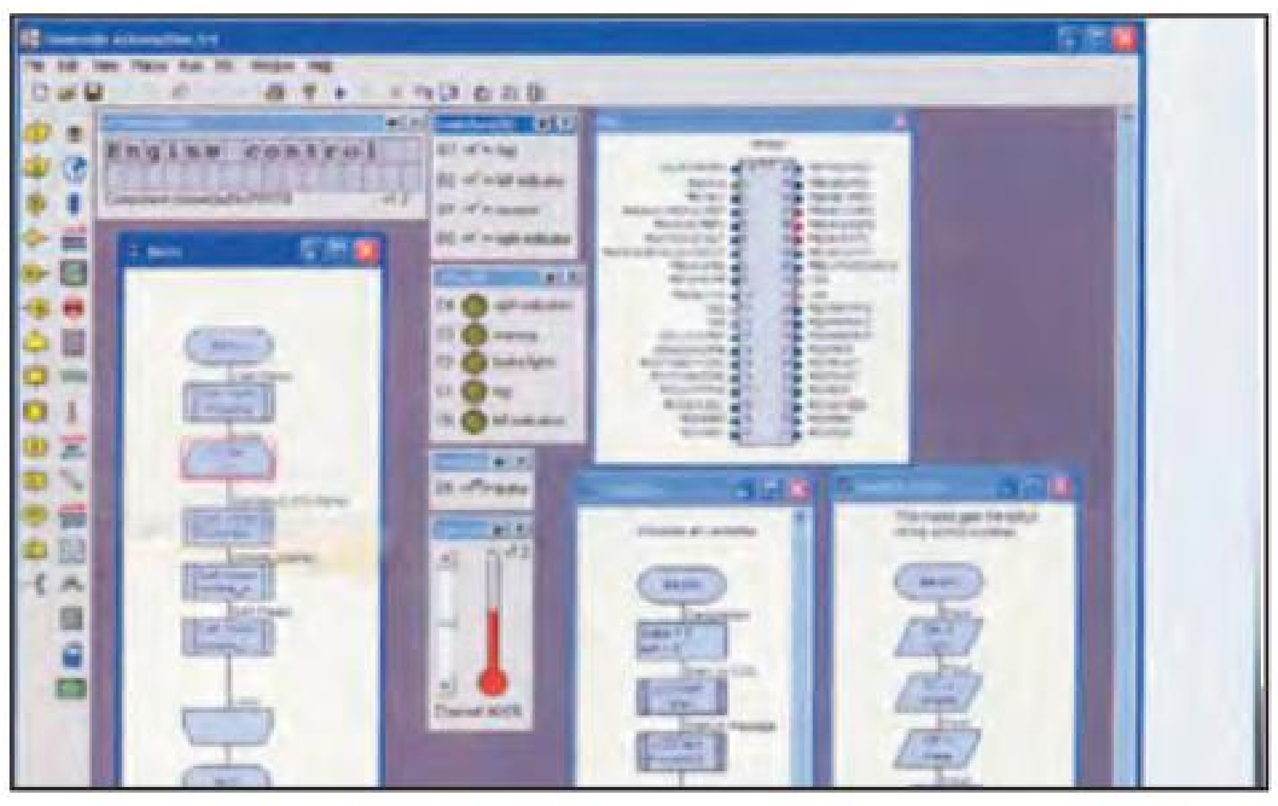

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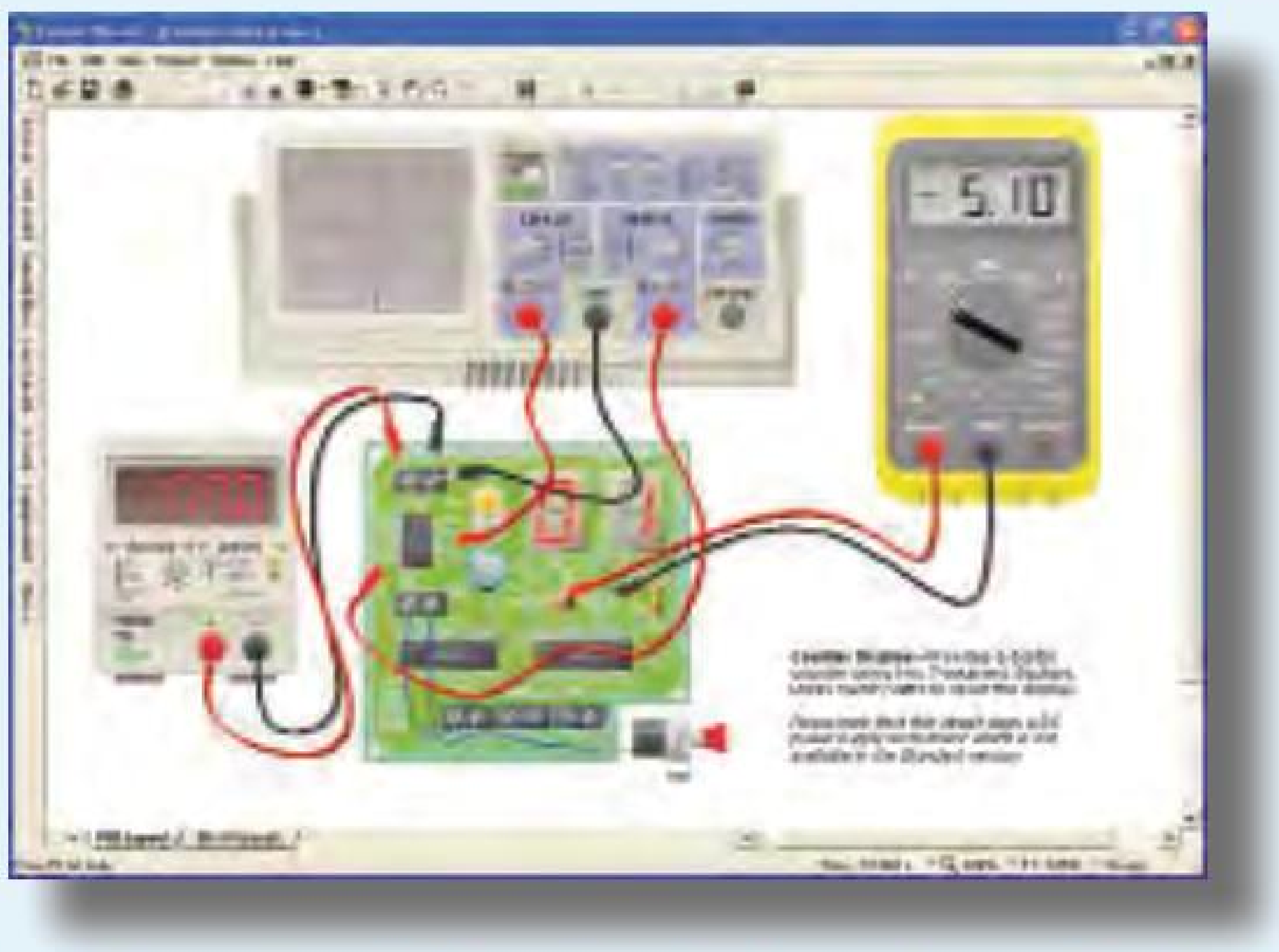

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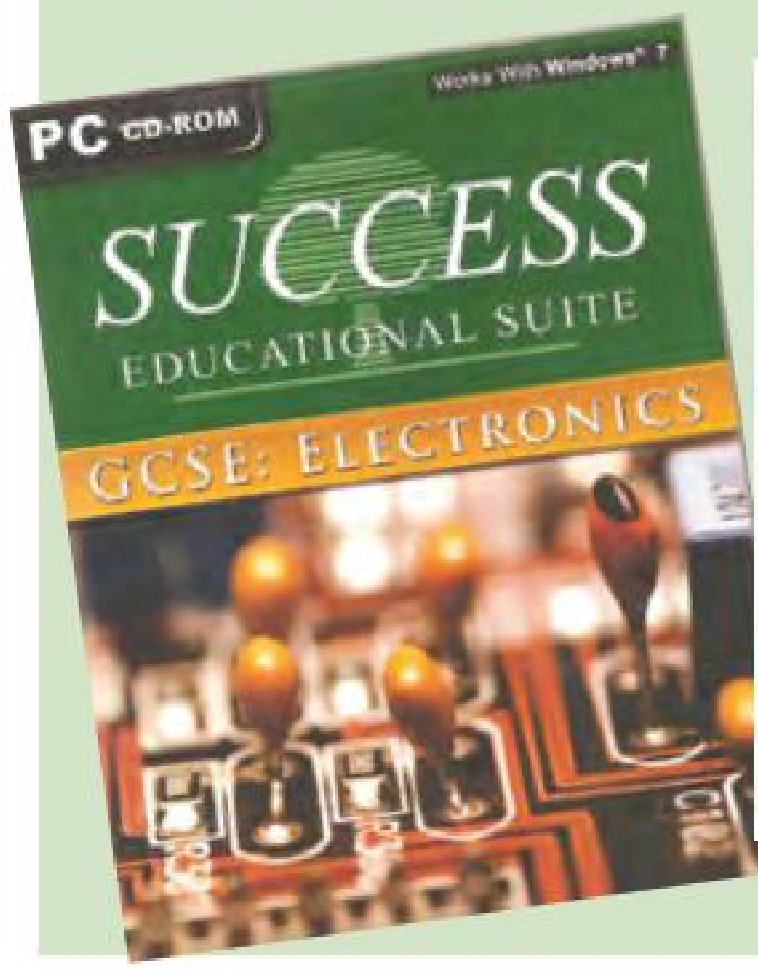

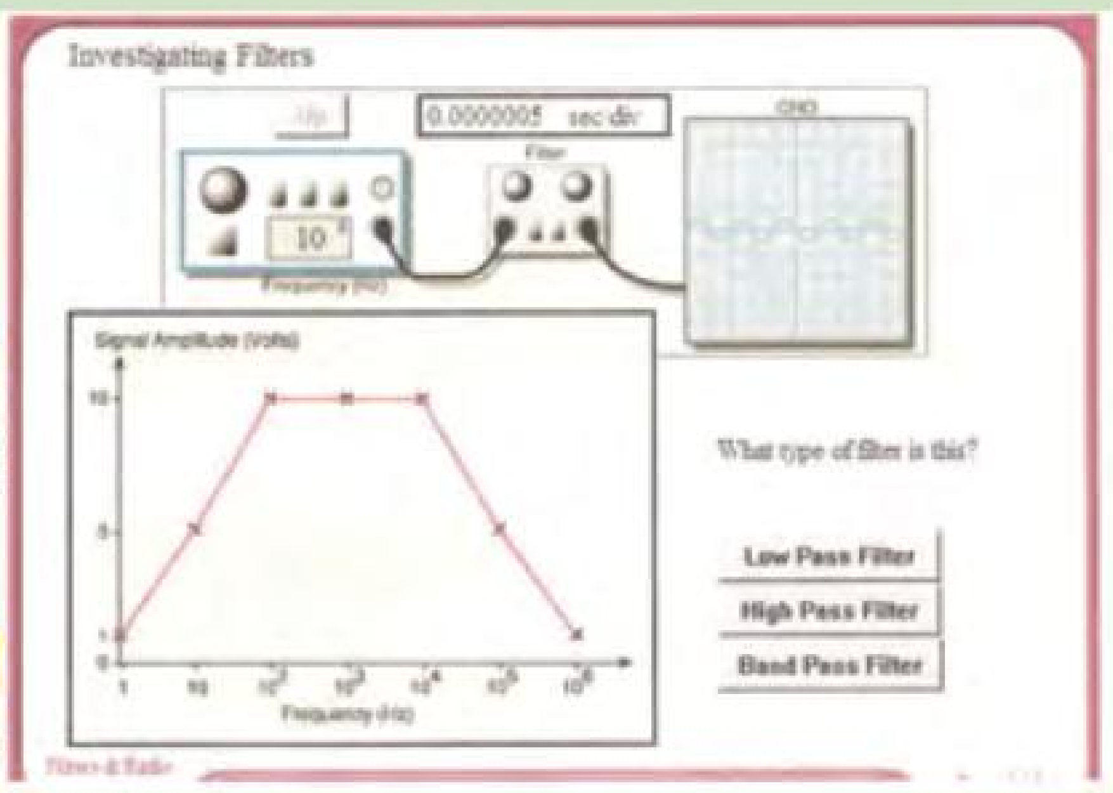

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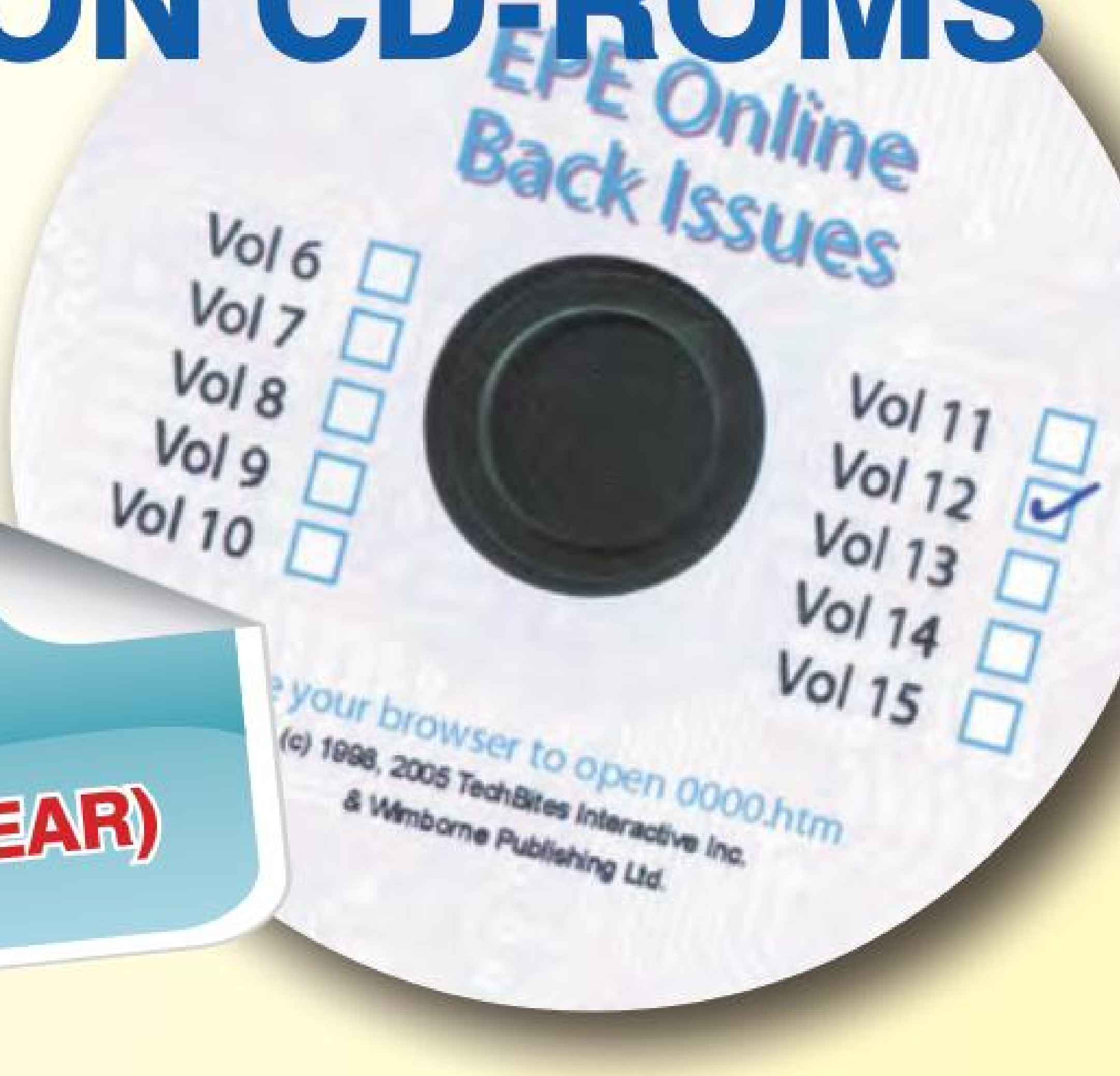
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# Max's Cool Beans

By Max The Magnificent

### Ooh, shiny!

I'm almost afraid to tell you that I've started a new project. Yes, I know I promised myself that I would complete some of my ongoing creations before commencing anything new, but I'm a weak man and I simply cannot help myself.

This all started when I saw the *Big Hex Machine* (**http://bit.ly/2hXZmlk**). This little beauty was designed and built by the staff and students in the Computer Science Department at Bristol University. 'Ooh,' I thought to myself, 'I'd like to build something like that.'

Next I saw the *Megaprocessor* (**http://bit.ly/2h7d0An**). This magnificent monster is the creation of one of my techno-dweeb-heroes, James Newman. It weighs in at around half a ton and boasts 42,400 transistors, 50,500 resistors, 10,500 LEDs, and 272,300 hand-soldered joints (you can visit the *Megaprocessor* in its new home at the Centre for Computing History in Cambridge). 'Ooh,' I thought to myself, 'I'd like to build something like that.'

I might still have been able to restrain myself, until a friend reminded me of something I'd seen ages ago, but that had been lost in the mists of time – *The Clock* (**http://bit.ly/1ws7I2x**), which was created by technologic-artist Gislain Benoit. This digital electronic timepiece is created out of discrete components: 340 transistors, 346 resistors, 1161 diodes, 60 red LEDs, and six 7-segment displays. Perhaps the most amazing thing about this little rascal (*The Clock*, not Gislain) is that the components are 'air-wired'; ie, soldered directly together without a printed circuit board. I bet you know what happened next... 'Ooh,' I thought to myself, 'I'd like to build something like that.'

But it was when I saw Gislain's *The Tower* (**http://bit.ly/1DAVISP**) that I exclaimed 'Ooh, Shiny!' and all was lost (Fig.1). Also a timepiece, this little scamp comprises 393 transistors, 333 resistors, 1,415 LEDs, and six 7-segment displays. Once again, these components are air-wired together, but this time they are presented in a tall glass cylinder. The idea is that, as the various digital elements perform their magic, you can observe what's happening by the state of the LEDs as the data ripples through the digital registers and logical functions.

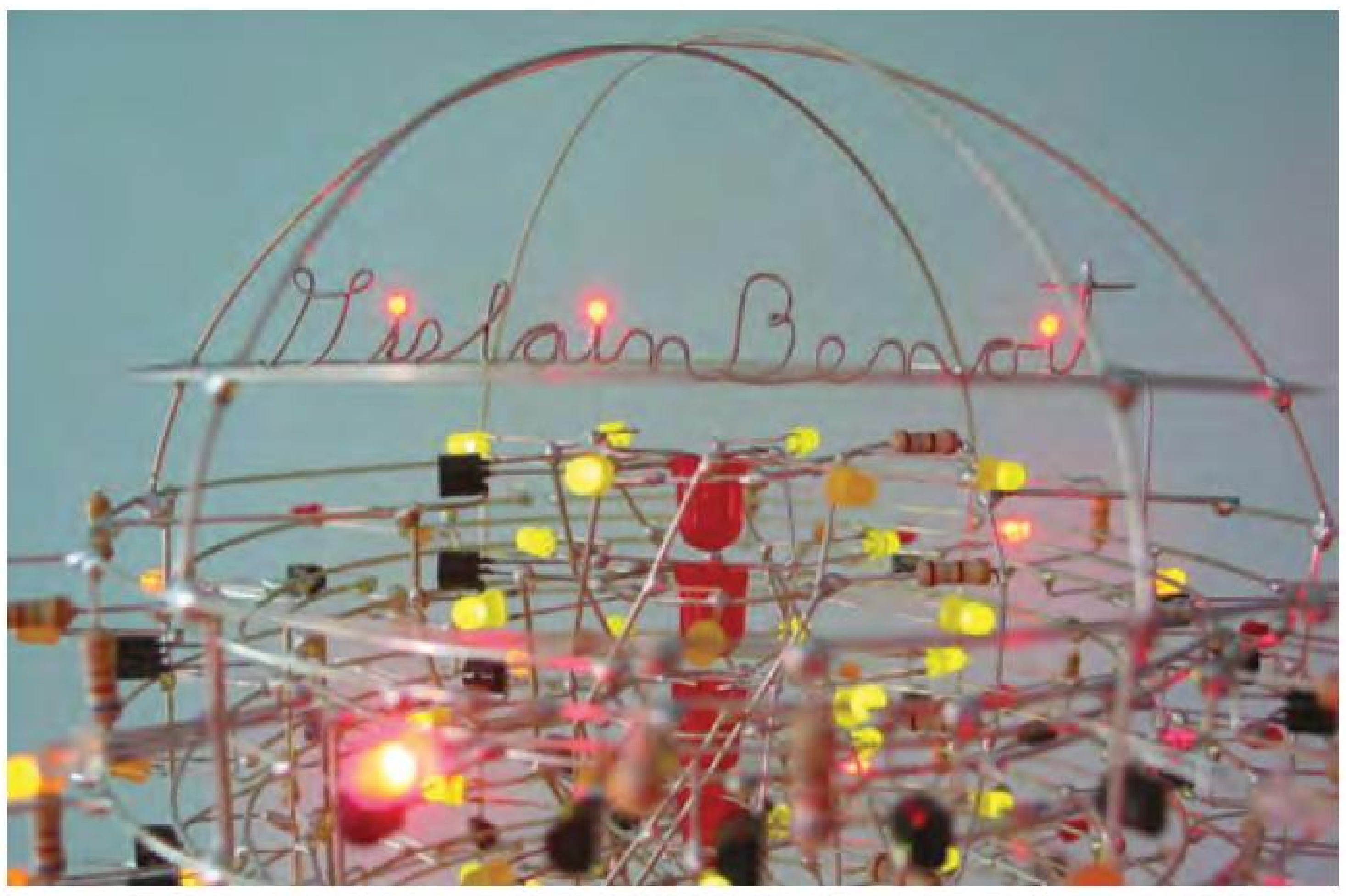

*Fig.1. Gislain Benoit's magnificent 'air-wired' clock*

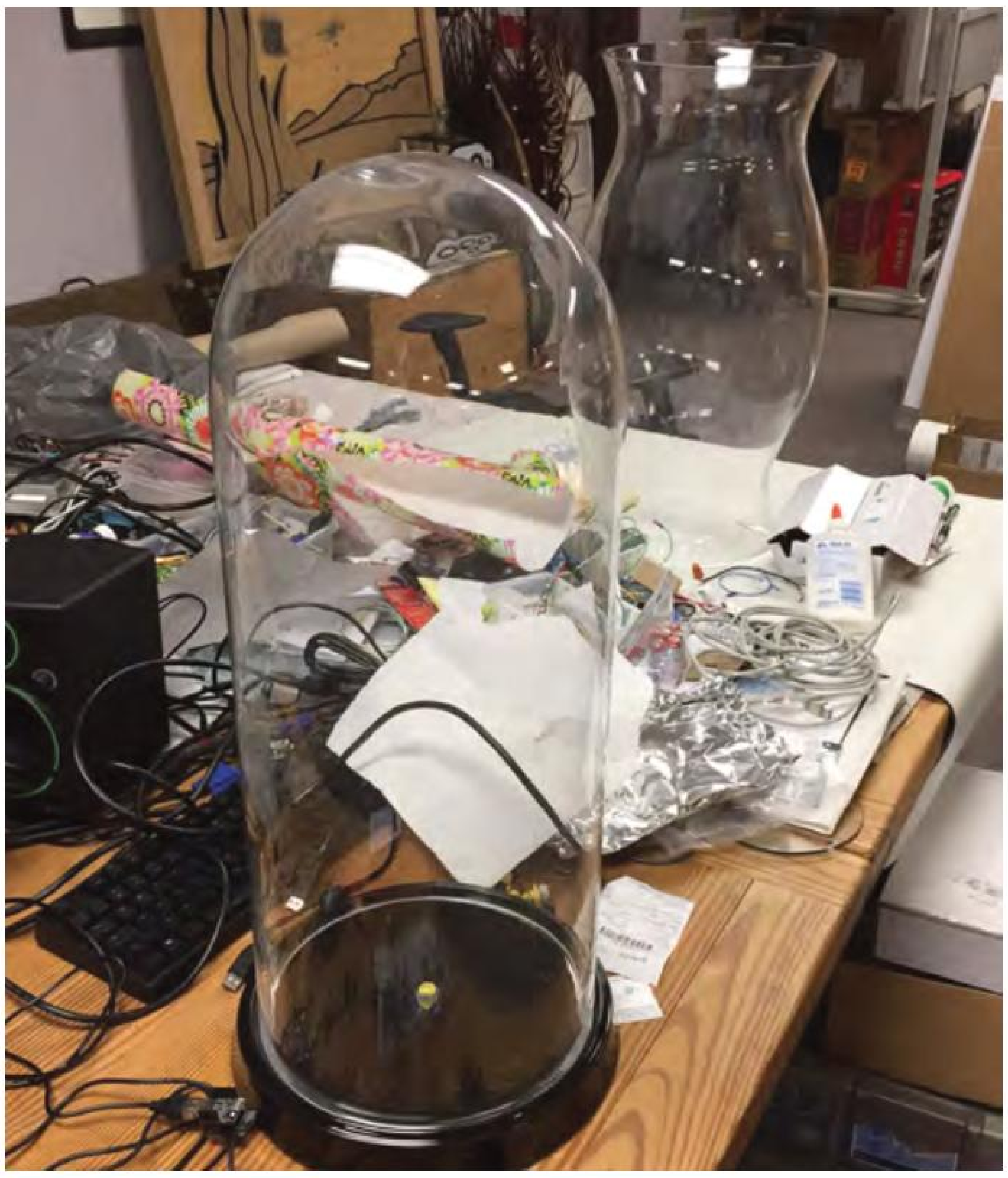

*Fig.2. One of these glass containers will be the future home of 'The Brain'*

### A bit of a Brainiac

By this time, I was practically jumping up and down and bouncing off the walls in excitement. But I don't want to simply re-create what someone else has done, and I fear Gislain has pretty much cornered the market on the air-wired clock front. Thus it was that I decided to create *The Brain* in the form of an artificial neural network. As part of this, I also plan to include lots of discrete components in the form of resistors and LEDs; I also plan on 'air-wiring' everything together; and I also plan on presenting my creation in a glass cylinder.

It was obvious that my first step should be to acquire the glass cylinder, thereby saving me from having to think about the complicated part. After rooting around on the web, I was initially a little disheartened because everything I saw was very expensive, but then I found a rather nice one on eBay for around $100. While I was waiting for this to arrive, I was ~~dragged against my will~~ invited to go on a shopping expedition with my wife (Gina the Gorgeous), and blow me down if I didn't run across a curved specimen on sale for only around $50, so I snapped that up also. Fig.2 shows these two glass containers sitting on a workbench in the bay outside my office.

### Neurotic neurons

The idea is to create a three-dimensional array of electronic neurons, each of which will receive signals from, and pass signals to, other neurons, but will otherwise function independently and autonomously.

When I say 'three-dimensional array,' the 'array' part may be misleading because it implies regularity; maybe the term 'matrix' would be more appropriate. This is not to imply that the neurons won't be implemented in a regular fashion – the bottom line is that I simply haven't decided yet. I'm still bouncing ideas back and forth inside my poor old noggin – maybe I should create the neurons in layers, or it might be better to simply add them in one at a time in a higgledy-piggledy fashion. As always, I welcome any and all comments and suggestions.

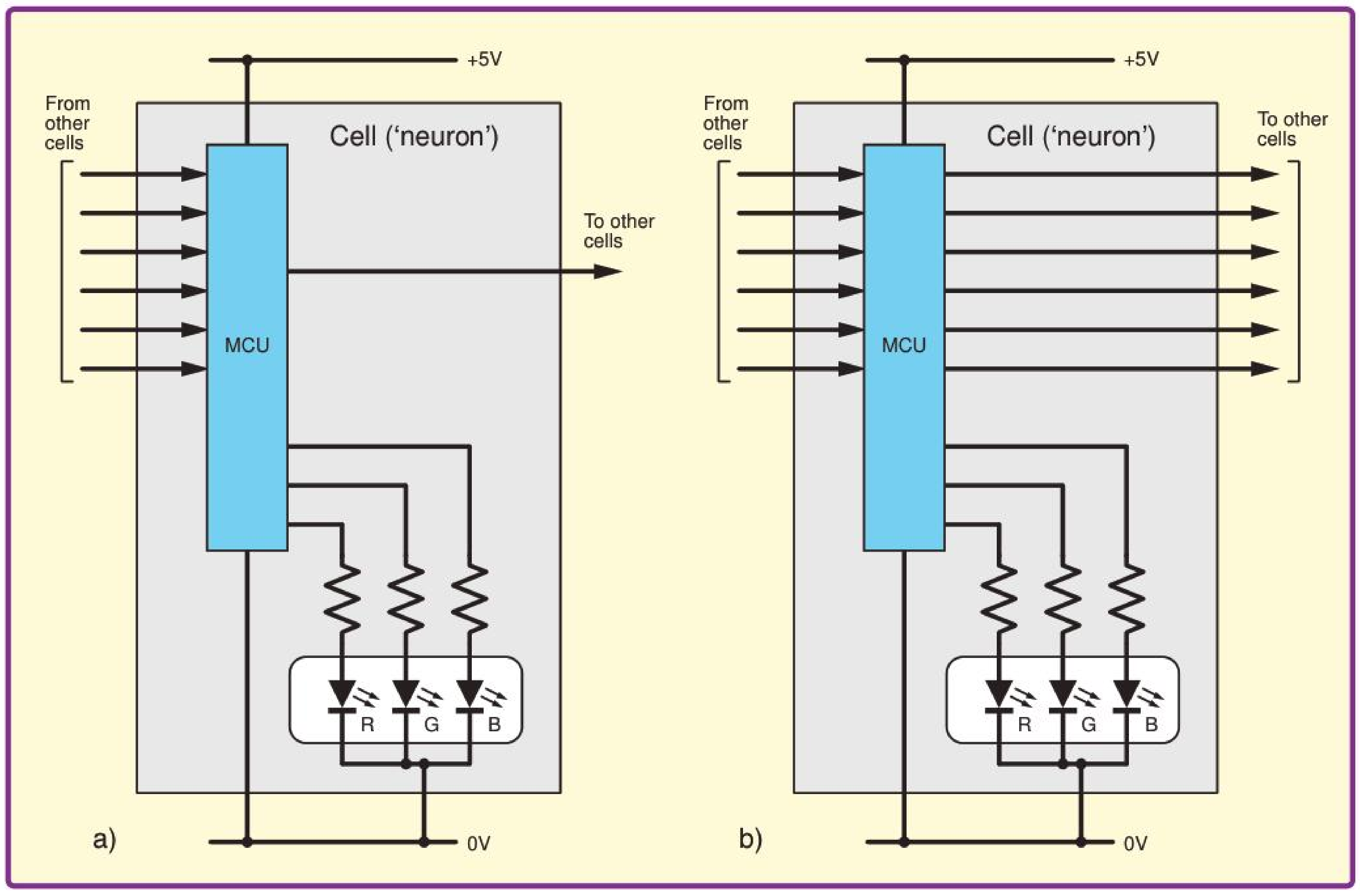

***Fig.3. Two alternative digital neuron implementations: a) multiple inputs, single output; b) multiple inputs, multiple outputs***

Originally, I had thought of creating each neuron as an analogue entity, but I've since decided to have a small digital processor at the heart of each cell, which will also contain a tri-colored LED. I may use surface-mount processors, in which case they will be mounted on tiny breakout boards, but everything else (LEDs, resistors) will be implemented using discrete lead-through-hole components that are air-wired together.

At some point you have to draw the line somewhere, so I've tentatively decided that each neuron will receive inputs from no more than six other neurons – I'm vaguely thinking that a neuron in the heart of the matrix can connect to neurons 'above,' 'below,' 'right,' 'left,' 'forward,' and 'backward,' if you see what I mean. Of course, this means that neurons on the periphery of the matrix will have fewer inputs.

If we decide to go with a purely digital implementation (Fig.3), then each input and output from a neuron will support logical 0 and 1 values. One possibility would be for each neuron to have six inputs from surrounding neurons, but only one output that is used to drive all six surrounding neurons. Another possibility would be for each neuron to have six outputs feeding back to the neurons driving its inputs.

Of course, this latter alternative does mean that we have a minimum of 12 signal wires connecting to each neuron, which is going to mean a lot of finagling and soldering. On the other hand, this also means that on power-up, we could initiate a 'discovery' process where each neuron determines it's relative location in the matrix (bottom, middle, top, outer edge, centre...).

On the other hand... suppose we just have *one* analogue input to each neuron and *one* pseudo-analogue (PWM) output from each neuron. If the output from each neuron contributed one-sixth of the full-range voltage, and the outputs from the six neurons driving the input of interest were summed, then each neuron could trigger when some pre-defined threshold was reached.

Oooh, there's so much to think about here. In my next column, we'll consider the various sensory inputs that we might use to provide stimulus to the brain, and also some of the different processing elements we could use to implement the neurons. Until then, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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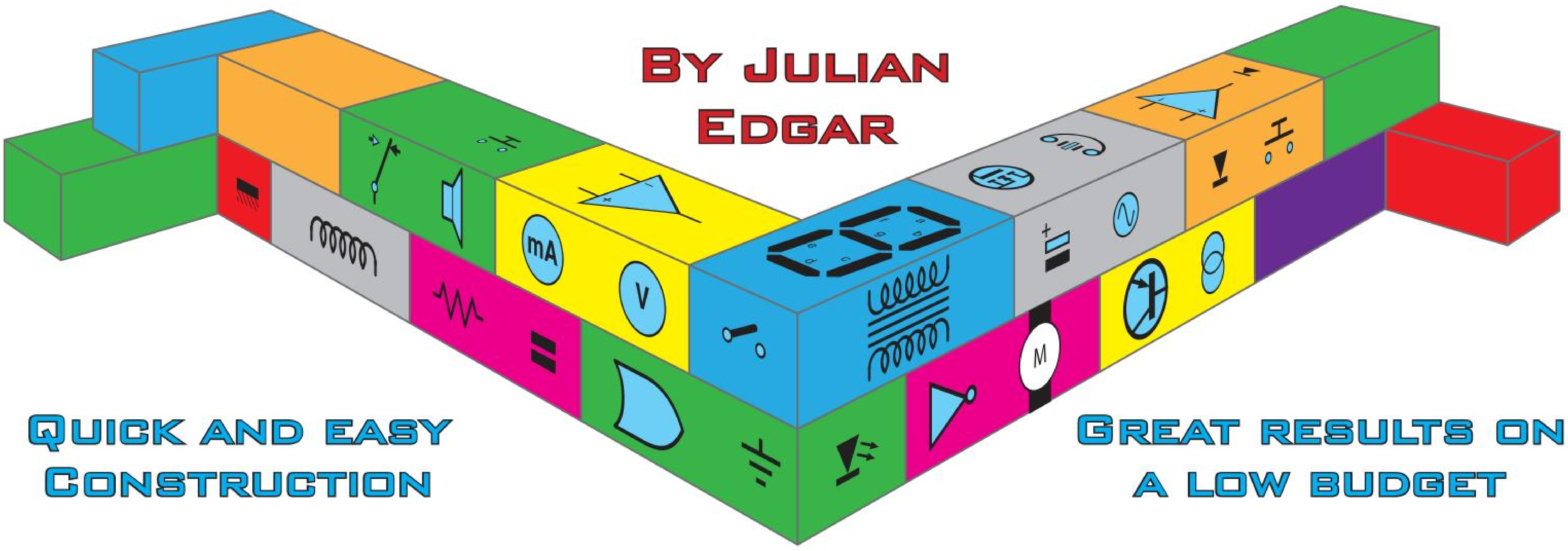

BY JULIAN EDGAR

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## HIGH FIVE!

**Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!**

Christmas has long gone, and took with it any residual health left in our bank balances! So this month, instead of focusing on one project I'm looking at five highly affordable eBay essentials. I've bought and used each one, so I can personally recommend you stock up on these tried-and-tested bargains.

### Battery monitoring

How often would a red/green indicator of battery voltage be useful? Lots of times, yes? Think of anything that has a battery but doesn't display battery voltage: toys, tools, torches, radios – the list goes on. Well, now there's a cheap pre-built answer – green for OK, red for replace (or charge) the battery.

*This tiny module uses a red/green LED to show battery voltage, and is good over the range of 6.5 – 20V.*

The tiny PCB is just 30 × 17 × 10mm and uses a single red/green LED. A multi-turn pot allows you to adjust the changeover voltage to be set from 6.5 – 30V. (However, at 20V and above the module grew warm – probably better to monitor batteries in the lower voltage range.)

The module has a hysteresis of about 0.2V. Above the set point it will show green, at the set point both the green and red parts of the LED are lit, and below the set point the LED shows red.

At 12V it draws about 10mA, so for best battery economy, operate it with a momentary pushbutton – just press the button whenever you want to check battery level.

Search on eBay under 'Battery low voltage warning module Adjustable Lithium NiMH NiCD ion phosphate' – at the time of writing, eBay item 141739123700. The module will cost you about £2.50, delivered to your letterbox.

### Light and sound warning

This is another product that falls into the category – 'when will I need one?', not 'will I ever need one?'. It's a warning light that incorporates an audible alarm. Connect 12V (either polarity) and the two LEDs will flash and the high-pitched buzzer will sound.

Note that when first triggered, the light and buzzer will be activated for a longer initial period (to get your attention), and then the follow-up flashes and sound are quicker.

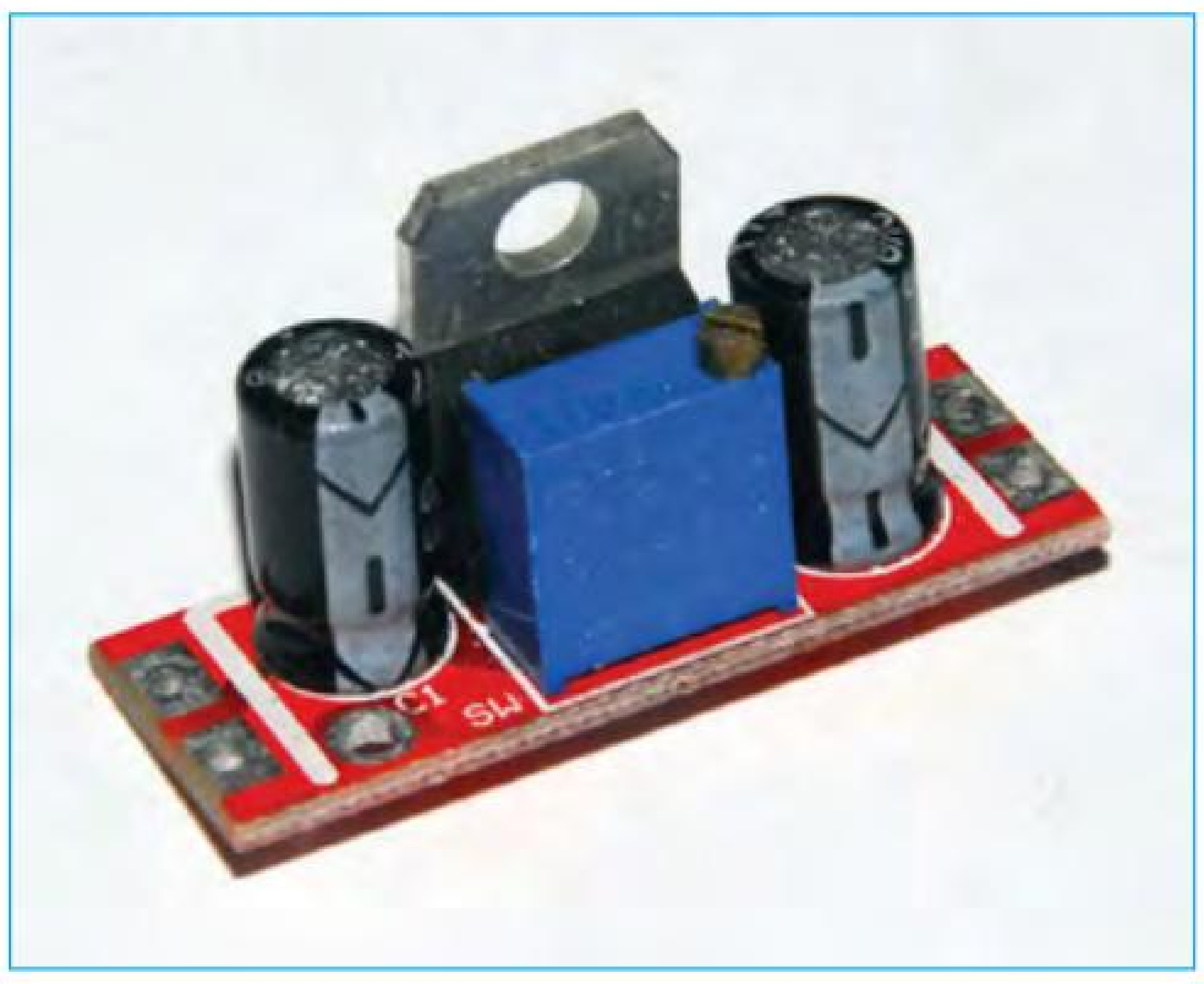
The killer advantage is the price – around £4 for five of these units, again with post included. Search under '5x DC 12V 22mm Red LED Power Indicator Light Signal with Buzzer' – at the time of writing, eBay item 181692862007.

*This warning device uses dual LEDs and a beeper to alert the operator. It nominally operates off 12V and will set you back only £4 for five of them.*

### High quality alligator clip hook-up leads

I like these so much that I've ended up buying three sets of them! So what are they? High quality, well insulated, 1m-long leads with alligator clips at each end. And, unlike the cheap versions of these leads widely available on eBay, these are durable and will take currents of up to 5A. In each set,

*This pic shows only one of them, but actually you get five different 1m-long leads, equipped with alligator clips at each end. These are good-quality high-current leads that in extended use have proved to be durable and effective. You'll pay a bit over £11 for a set of five.*



*This module uses a traditional LM317 voltage regulator configured with an adjustable output. It's ideal for providing regulated voltages in low-current configurations.*

you get five of the leads – green, yellow, black, red and blue.

So why are they so useful? I use them to connect chargers to batteries, to quickly and easily connect my bench power supply to circuits under test, to connect speaker drivers (again under test) to an audio oscillator – and so on. I've been using my first set continuously for more than 12 months and nothing has broken or failed.

The leads can be found by searching under '5pcs 3ft 1M high current 53mm Alligator Test Probe Clamp Clip Cable 5 Colors' – at the time of writing, eBay item 261821898007. They'll cost you a bit over £11. (Don't confuse them with the 50cm long leads that have very thin gauge wire and really poor alligator clips. Those ones cost about £2 – they're not worth even that.)

### Adjustable voltage regulator

How often do you need a low-current voltage regulator? The answer to that question is: lots! OK, many of us keep three-terminal linear regulators on the shelf. They're cheap and easy – but, by the time you mount the regulator, add some capacitors (and resistors if you want to set the output level), you've spent longer than you should have. This is especially true when an adjustable LM317 pre-built board is available for just 99p, post included. (Or do as I did, and buy five of them to put on the shelf – just £3.80 total)

The LM317 is rated at up to 1.5A output, but depending on the required voltage drop, will probably require a heatsink to achieve this. It's happy working with an output range of 1.25 to 37V, but remember that the input voltage will always need to be about 3V higher than the required output.

The board is clearly marked with solder pads for input and output, and the multi-turn pot allows fine adjustment of the output voltage. While a heatsink is not supplied on the module I bought, it is easily attached, as the regulator tab is quite accessible.

To find the module, search under 'Low Ripple Buck Linear Regulated Power Supply LM317 Module' – at the time of writing, eBay item 111826121404.

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*These scales are printed on aluminium and are ideal for use behind potentiometer knobs. They're 40mm in diameter and the printing is of good quality – here it's covered in a layer of protective plastic film that you peel off after installation.*

### Potentiometer knob scales

Here are some things that I've not seen for sale recently, except on eBay – they're scales that fit behind knobs on potentiometers. I thought that they looked interesting, bought some – and then found I use them a lot.

The scales are marked with ten-unit major increments from 0 – 100. They're 40mm in diameter and use a 10mm mounting hole. In use, you position them behind the pot's mounting nut and then rotate them until they match the sweep of the pot. The printing is good quality (protected by a plastic film that can be peeled off) and they're most effective with knobs having a maximum skirt diameter of 25mm or less.

Expect to pay just over £3 for ten of them, and search under 'Rheostat Variable Transformer Potentiometer 0-100 Control Dial Face Plate 10pcs' – at the time of writing, eBay item 191626747804.

### Next month

Something a little different – rather than look at individual products purchased online, I'll cover a complete project built from parts sourced very cheaply that revolutionised the usefulness of an old machine in my workshop.

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## CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

**NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.**

| PROJECT TITLE | ORDER CODE | COST |
|---|---|---|
| NOV '15 | | |
| The Currawong – Part 1 | | |
| – Main Board | 01111141 | £47.20 |
| – Front Panel | 01111142 | £24.75 |
| – Rear Panel | 01111143 | |
| 48V Dual Phantom Power Supply | 18112141 | £9.37 |
| Programmable Mains Timer With Remote Switching | | |
| – Main Board | 19112141 | £11.80 |
| – Front Panel | 19112142 | £16.40 |
| DEC '15 | | |
| TDR Dongle For Oscilloscopes | 04112141 | £7.20 |
| High-Energy Multi-Spark CDI For Performance Cars | 05112141 | £11.80 |
| JAN '16 | | |
| Isolating High Voltage Probe For Oscilloscopes | 04108141 | £11.80 |
| The Currawong – Part 3 | | |
| – Remote Control Board | 01111144 | £6.95 |
| FEB '16 | | |
| Spark Energy Meter – Main Board | 05101151 | £20.75 |
| – Zener Diode Board | 05101152 | £7.50 |
| – Calibrator Board | 05101153 | |
| APRIL '16 | | |
| Appliance Insulation Tester | 04103151 | £11.80 |
| – Front Panel | 04103152 | £11.80 |
| Low Frequency Distortion Analyser | 04104151 | £7.50 |
| MAY '16 | | |
| 2-Channel Balanced Input Attenuator for Audio Analysers and Digital Scopes | | |
| – Main Board | 04105151 | £16.40 |
| – Front Panel | 04105152 | £20.75 |
| – Rear Panel | 04105153 | |
| Appliance Earth Leakage Tester | | |
| – Main Board | 04203151 | £16.40 |
| – Insulation Board | 04203152 | |
| – Front Panel | 04203153 | £16.40 |
| 4-Output Universal Voltage Regulator | 18105151 | £7.50 |
| JUNE '16 | | |
| Infrasound Snooper | 04104151 | £7.50 |
| Audio Signal Injector and Tracer | 04106151 | £9.64 |
| – Shield Board | 04106153 | £7.48 |
| – Demodulator Board | 04106152 | £5.36 |
| Champion Preamp | 01109121/22 | £8.29 |
| JULY '16 | | |
| Driveway Monitor – Detector Unit | 15105151 | £11.80 |
| – Receiver Unit | 15105152 | £7.50 |
| USB Charging Points | 18107151 | £5.00 |
| AUG '16 | | |
| Low-cost Resistance Reference | 04108151 | £5.36 |
| USB Power Monitor | 04109121 | £12.00 |
| SEPT '16 | | |
| LED Party Strobe | 16101141 | £9.80 |
| Speedo Corrector | 05109131 | £12.00 |

| PROJECT TITLE | ORDER CODE | COST |
|---|---|---|
| OCT '16 | | |
| Arduino-Based USB Electrocardiogram | 07108151 | £9.79 |
| 100W Switchmode/Linear Bench Supply – Part 2 | 18104141 | £20.83 |
| NOV '16 | | |
| Fingerprint Access Controller – Main Board | 03109151 | £12.88 |
| – Switch Board | 03109152 | |
| DEC '16 | | |
| Universal Loudspeaker Protector | 01110151 | £12.88 |
| 9-Channel Infrared Remote Control | 15108151 | £16.42 |
| Revised USB Charger | 18107152 | £5.36 |
| JAN '17 | | |
| High-performance Stereo Valve Preamplifier | 01101161 | £17.75 |
| High Visibility 6-Digit LED Clock | 19110151 | £16.42 |
| FEB '17 | | |
| Solar MPPT Charger/Lighting Controller | 16101161 | £17.75 |
| Turntable LED Strobe | 04101161 | £7.60 |
| MARCH '17 | | |
| Speech Timer for Contests & Debates | 19111151 | £16.42 |

*** See NOTE left regarding PCBs with eight digit codes ***

**Please check price and availability in the latest issue.**
**A large number of older boards are listed on, and can be ordered from, our website.**
Boards can only be supplied on a payment with order basis.

**Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.**

## EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at:
**www.epemag.com**

## PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email **fay.kearn@wimborne.co.uk** stating which masters you would like.

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## ADVERTISERS INDEX

BRUNNING SOFTWARE . . . . . Cover (ii)
CRICKLEWOOD ELECTRONICS . . . . . 72
ESR ELECTRONIC COMPONENTS . . . . . 6
EURO CIRCUITS . . . . . 58
HAMMOND ELECTRONICS Ltd . . . . . 17
iCSAT . . . . . 61
JPG ELECTRONICS . . . . . 72
LABNATION . . . . . 57
LASER BUSINESS SYSTEMS . . . . . 69
LEDLABS . . . . . 69
MICROCHIP . . . . . Cover (iii), 10 & 53
PEAK ELECTRONIC DESIGN . . . . . Cover (iv)
PICO TECHNOLOGY . . . . . 43
POLABS D.O.O. . . . . . 27
QUASAR ELECTRONICS . . . . . 2/3
STEWART OF READING . . . . . 58
TAG-CONNECT . . . . . 61

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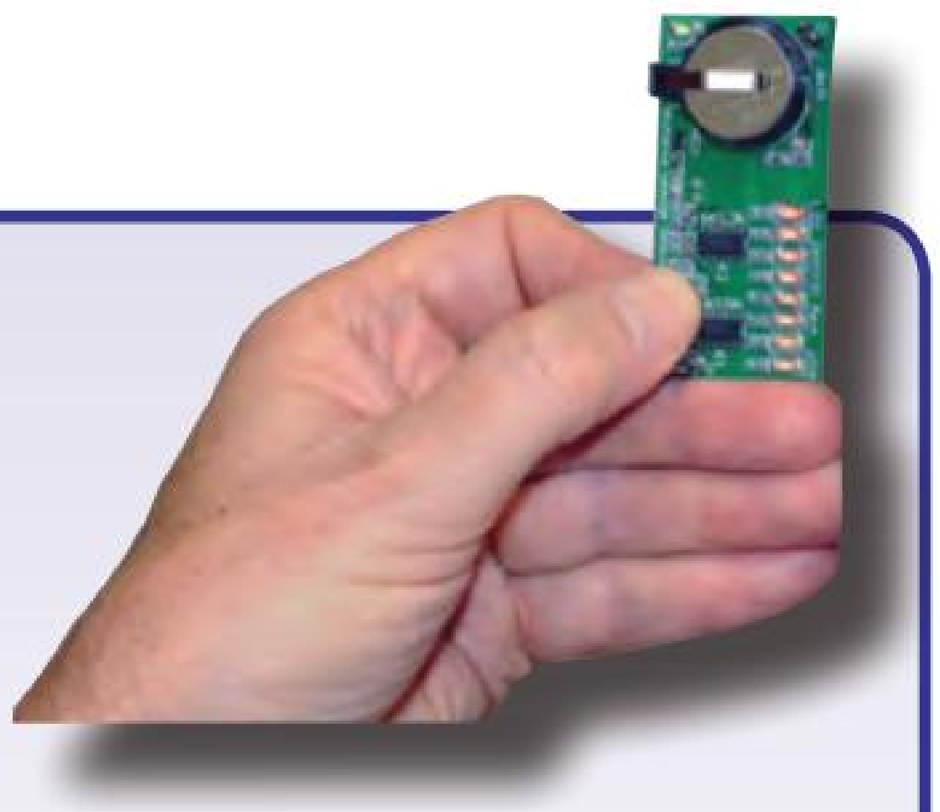
# Next Month

Content may be subject to change



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### Arduino Multifunction 24-Bit Measuring Shield – Part 1

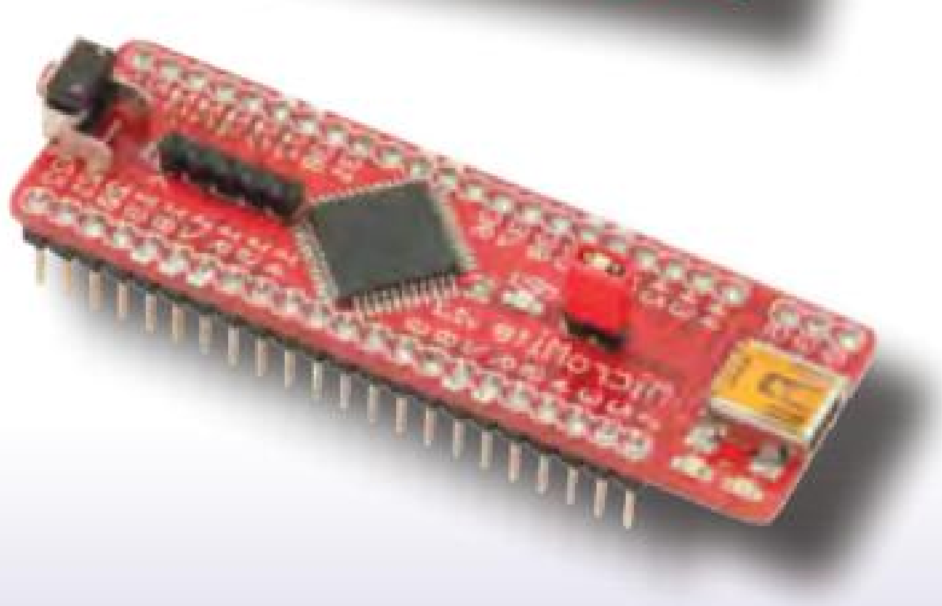
Here's a superb low-cost PC-linked measuring system project which provides four accurate DC voltage measurement ranges, together with an audio frequency level and power meter, plus an optional RF level and power meter that can operate to 500MHz.

### Battery Pack Cell Balancer

Many multi-purpose chargers can handle lithium-ion, lithium-polymer or LiFePO4 batteries. But they may not balance the charge between individual cells and this can lead to incomplete charging and premature failure. This small device solves this by providing the balancing function separately. Plus, it is suitable for use with the *MPPT Solar Lighting Charger/Controller* published in the previous two issues.

### Meet the mighty Micromite – Part 3

The Micromite is an amazing device. A low-cost microcontroller programmed in a Microsoft-compatible version of BASIC with floating point, arrays and extensive string handling. In Part 3, we examine programming the Micromite in MMBasic.



### PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks, PIC n' Mix* and *Net Work.*

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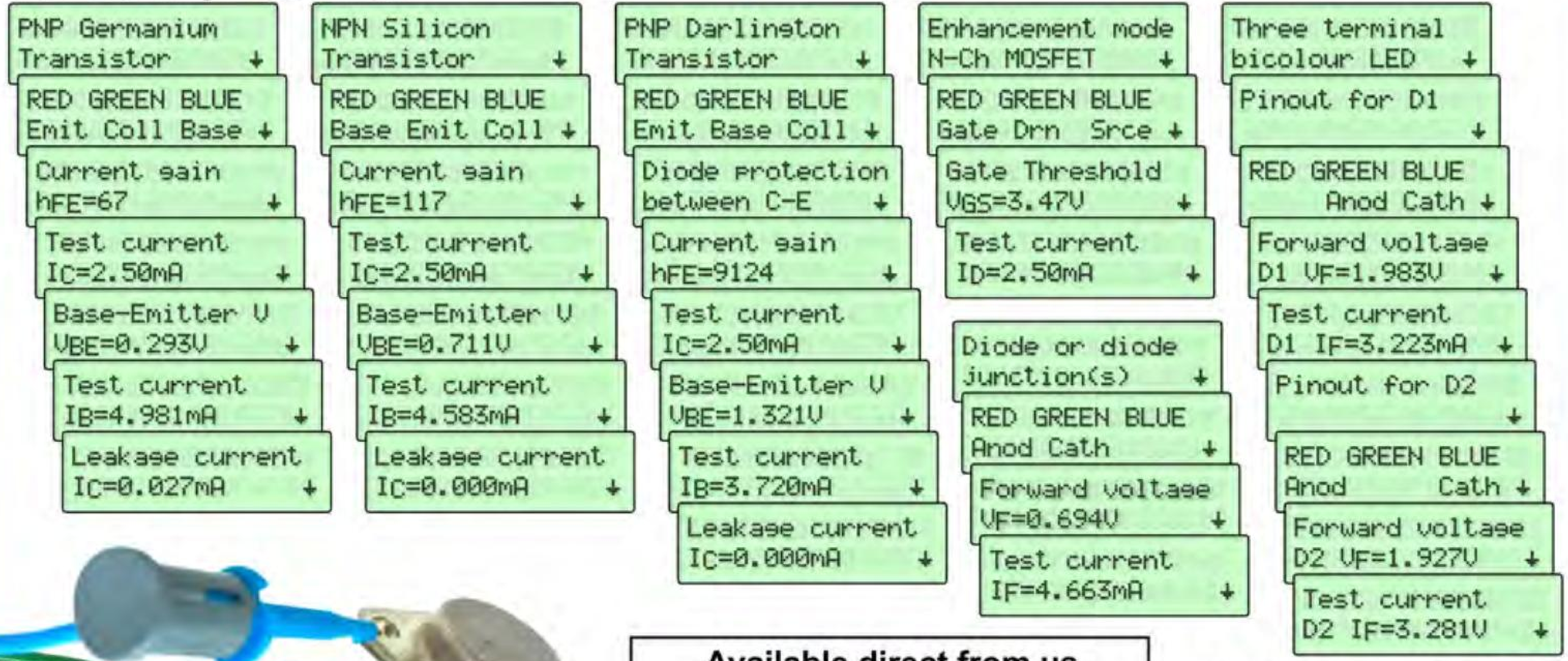

```
PNP Germanium
Transistor       ↓
RED GREEN BLUE
Emit Coll Base   ↓
Current gain
hFE=67           ↓
Test current
IC=2.50mA        ↓
Base-Emitter V
VBE=0.293V       ↓
Test current
IB=4.981mA       ↓
Leakage current
IC=0.027mA       ↓

NPN Silicon
Transistor       ↓
RED GREEN BLUE
Base Emit Coll   ↓
Current gain
hFE=117          ↓
Test current
IC=2.50mA        ↓
Base-Emitter V
VBE=0.711V       ↓
Test current
IB=4.583mA       ↓
Leakage current
IC=0.000mA       ↓

PNP Darlington
Transistor       ↓
RED GREEN BLUE
Emit Base Coll   ↓
Diode protection
between C-E      ↓
Current gain
hFE=9124         ↓
Test current
IC=2.50mA        ↓
Base-Emitter V
VBE=1.321V       ↓
Test current
IB=3.720mA       ↓
Leakage current
IC=0.000mA       ↓

Enhancement mode
N-Ch MOSFET      ↓
RED GREEN BLUE
Gate Drn  Srce   ↓
Gate Threshold
VGS=3.47V        ↓
Test current
ID=2.50mA        ↓

Diode or diode
junction(s)      ↓
RED GREEN BLUE
Anod Cath        ↓
Forward voltage
VF=0.694V        ↓
Test current
IF=4.663mA       ↓

Three terminal
bicolour LED     ↓
Pinout for D1
                 ↓
RED GREEN BLUE
     Anod Cath   ↓
Forward voltage
D1 VF=1.983V     ↓
Test current
D1 IF=3.223mA    ↓
Pinout for D2
                 ↓
RED GREEN BLUE
Anod      Cath   ↓
Forward voltage
D2 VF=1.927V     ↓
Test current
D2 IF=3.281V     ↓
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